CHAPTER 10 Sea coast

10.1 Outline of Study

10.1.1 Purpose of Study

The comprehensive bed load sediment management is to manage totally the issues of sediment transport in continuous each area from river basin to river mouth and sea coast, which is one of important view point to establish the flood control master plan in Nadi River basin.

In this chapter, the influence of erosion and deposition caused by littoral drift sand transport after implementation of the flood control plan is predicted by calculation model of Sea coast Profile Change. And the most appropriate flood control plan is determined and its influence is assessed.

10.1.2 Work Flow of Study

The study is divided into three (3) steps," Field Investigation of Sea coast", "Reproduction Analysis of Present Situation" and "Prediction calculation on Flood Control plan", as shown Figure 10-1.

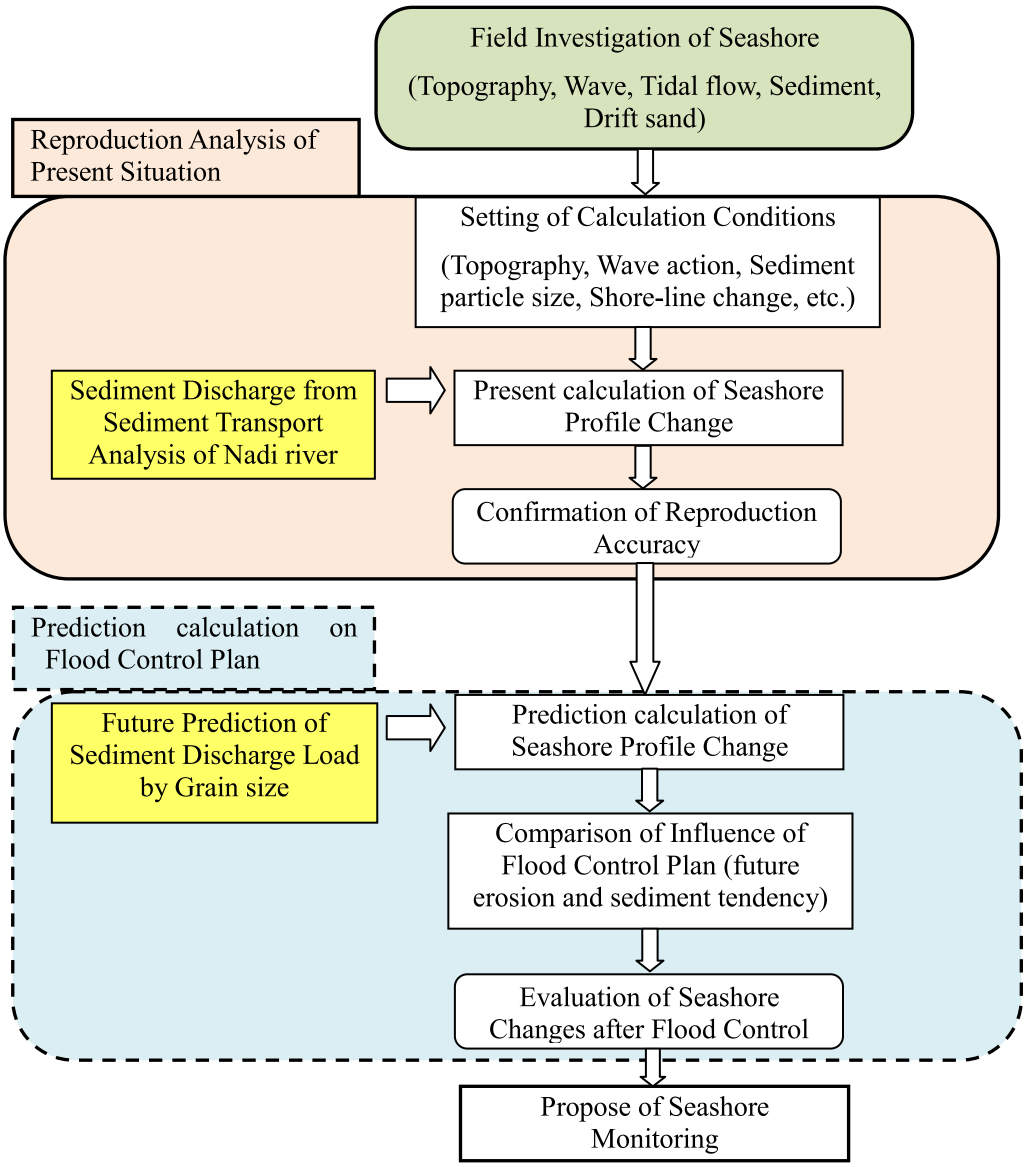


Figure 10-1 Work Flow of Sea coast Profile Change

In the Field Investigation of Sea coast, the topographical survey, wave and tidal flow, sediment , littoral drift sand are investigated in two times of dry season and rainy season.

In the Reproduction Analysis of Present Situation, the calculation model of sea coast profile change is carried out by inputting sediment discharge data under the present conditions, for confirmation of reproduction accuracy. The sediment data are estimated by Sediment Transport Analysis at river mouth in Nadi River from the past to present.

Future change of sea coast profile after flood control, the future change is calculated based on the sediment discharge of each flood control plan, and the erosion and sediment tendency is compared with each other for evaluation of the influence to sea coast.

According to the evaluation, the effective management method is proposed for the sustainable sea coast management such as monitoring observation in the sea coast with tendency of erosion and so on, if necessary.

10.2 Collection of the Basic Information on the Sea coast

10.2.1 Outline of the Survey

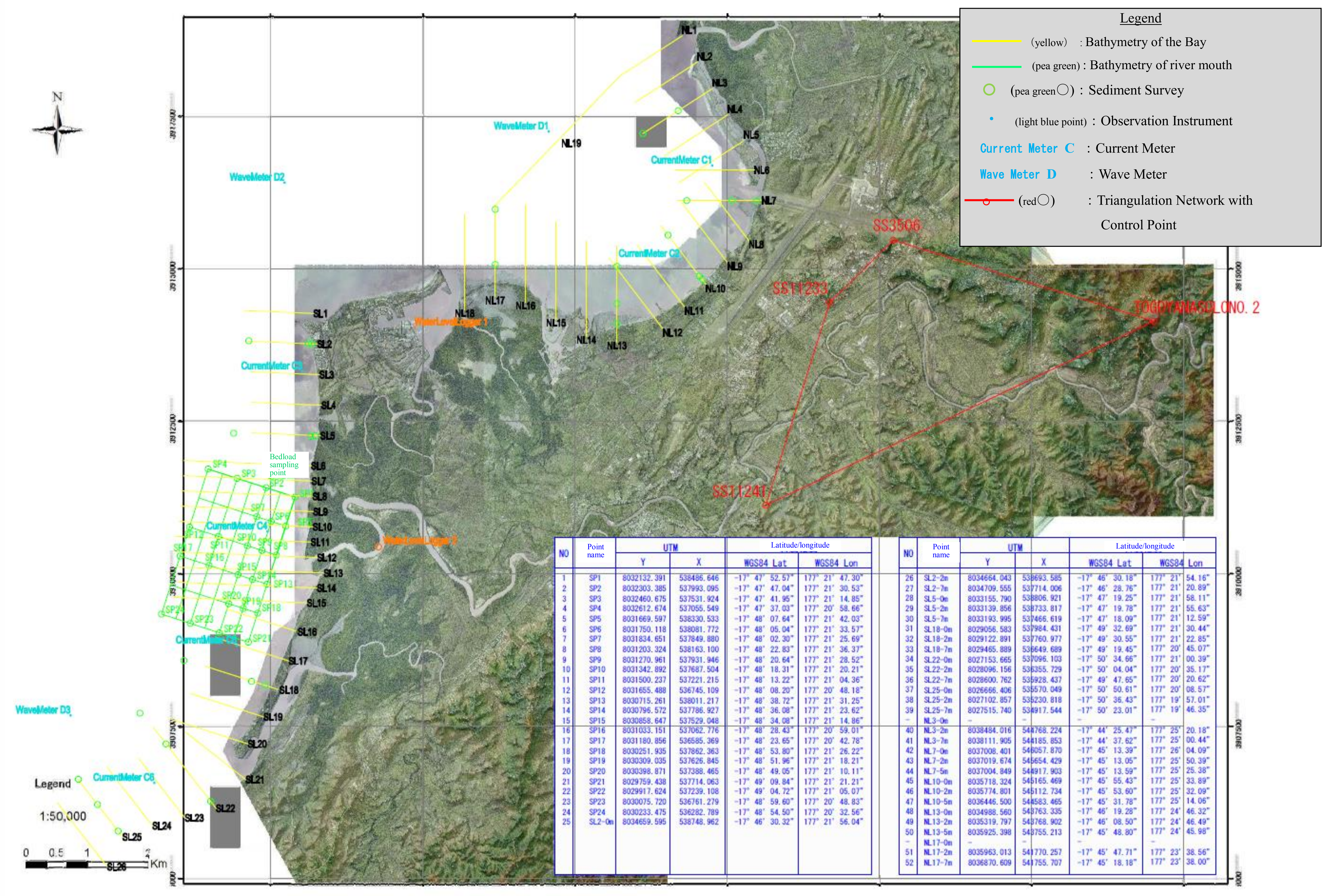
The present sea coast characteristics are understood and the change of sea coast after implementation of flood control plan is predicted and evaluated.

The field investigation was conducted in order to collect the basic data required for analysis such as wave, tidal flow, littoral drift sand, sediment and so on.

Table 10-1 Details of Survey Concerning Sea coast

Item	Investigation		Method	Remarks
Meteorology and marine phenomena	Wind (sea and land) Wave	Wind velocity and direction near sea coast Records of past cyclone and storm surge	Data collection	Meteorology data including wind (FMS) Ocean wave data(Global wave estimation data base , past 5 years)
	Tide and high tide	Tide table Chronological tidal change	Data collection	FIJI NAUTICAL ALMANAC Tide observation data(Meteorological Department of Government of Australia)
	Existing sea coast structure	Survey of existing structure	Survey of shape and structure of bank protection and jetty	Field survey
Sea coast topography	Sea coast profile Sea bed topography	Analysis of past data Sea coast line survey Collection of existing data Bathymetric survey	Photo analysis Field survey by RTK-GPS Collection of hydrographic chart Bathymetry with echo sounder	Aerial photographs and satellite images Field reconnaissance Arrangement of chart data Arrangement of cross-section, bathymetric maps
Characteristics of drift sand	Sediment discharge from the river Sediment at river mouth	Sediment discharge from river mouth Particle size at river mouth	Observation of discharge and velocity Sampling at river mouth	See Chapters 8 and 9 for details
	Environment of sea coast	Sea coast currents Tidal currents	Field observation of wave height and direction Field observation of current	Wave meters, 3 units installed (for the measurement for 15 days and nights and 30 days and nights) Current velocity and direction meters: 6 units installed (for the measurement for 15 days and nights and 30 days and nights)
	Observation of suspended solids	Measurement of suspended sediments	Sediment sampler 11units	Measurement of the weights of sediment in sampler
Characteristics of the sediment on the seabed	Sampling of surface sediment	Alongshore and cross-shore distribution	3 points at the shoreline, -2m, -5m on 10 survey lines + 24 locations near the river mouth + bed load samplers at 11 locations	Sampling by divers along the designated survey lines (No sampling at two locations, one in private land and the other in a mangrove forest)
	Soil tests of the surface sediment	Particle size distribution and, as reference, specific gravity, water content, LL/PL and loss on ignition	Sieve analysis: 63 points Sedimentation analysis: 34 points Analysis of specific gravity/water content: 38 points Loss on ignition and LL/PL: 38 points	Analyses conducted by local private laboratories

(The meteorological data measured daily at 9 a.m. at the Lautoka Monitoring Station were sorted and used in the survey.)



NO	Point name	UTM Y	UTM X	Latitude/longitude WGS84 Lat	Latitude/longitude WGS84 Lon
1	SP1	8032132. 391	538486. 646	-17° 47' 52. 57"	177° 21' 47. 30"
2	SP2	8032303. 385	537993. 095	-17° 47' 47. 04"	177° 21' 30. 53"
3	SP3	8032460. 675	537531. 924	-17° 47' 41. 95"	177° 21' 14. 85"
4	SP4	8032612. 674	537055. 549	-17° 47' 37. 03"	177° 20' 58. 66"
5	SP5	8031669. 597	538330. 533	-17° 48' 07. 64"	177° 21' 42. 03"
6	SP6	8031750. 118	538081. 772	-17° 48' 05. 04"	177° 21' 33. 57"
7	SP7	8031834. 651	537849. 880	-17° 48' 02. 30"	177° 21' 25. 69"
8	SP8	8031203. 324	538163. 100	-17° 48' 22. 83"	177° 21' 36. 37"
9	SP9	8031270. 961	537931. 946	-17° 48' 20. 64"	177° 21' 28. 52"
10	SP10	8031342. 892	537687. 504	-17° 48' 18. 31"	177° 21' 20. 21"
11	SP11	8031500. 237	537221. 215	-17° 48' 13. 22"	177° 21' 04. 36"
12	SP12	8031655. 488	536745. 109	-17° 48' 08. 20"	177° 20' 48. 18"
13	SP13	8030715. 261	538011. 217	-17° 48' 38. 72"	177° 21' 31. 25"
14	SP14	8030796. 572	537786. 927	-17° 48' 36. 08"	177° 21' 23. 62"
15	SP15	8030858. 647	537529. 048	-17° 48' 34. 08"	177° 21' 14. 86"
16	SP16	8031033. 151	537062. 776	-17° 48' 28. 43"	177° 20' 59. 01"
17	SP17	8031180. 856	536585. 369	-17° 48' 23. 65"	177° 20' 42. 78"
18	SP18	8030251. 935	537862. 363	-17° 48' 53. 80"	177° 21' 26. 22"
19	SP19	8030309. 035	537626. 845	-17° 48' 51. 96"	177° 21' 18. 21"
20	SP20	8030398. 871	537388. 465	-17° 48' 49. 05"	177° 21' 10. 11"
21	SP21	8029759. 438	537714. 063	-17° 49' 09. 84"	177° 21' 21. 21"
22	SP22	8029917. 624	537239. 108	-17° 49' 04. 72"	177° 21' 05. 07"
23	SP23	8030075. 720	536761. 279	-17° 48' 59. 60"	177° 20' 48. 83"
24	SP24	8030233. 475	536282. 789	-17° 48' 54. 50"	177° 20' 32. 56"
25	SL2-0m	8034659. 595	538748. 962	-17° 46' 30. 32"	177° 21' 56. 04"

NO	Point name	UTM Y	UTM X	Latitude/longitude WGS84 Lat	Latitude/longitude WGS84 Lon
26	SL2-2m	8034664. 043	538693. 585	-17° 46' 30. 18"	177° 21' 54. 16"
27	SL2-7m	8034709. 555	537714. 006	-17° 46' 28. 76"	177° 21' 20. 89"
28	SL5-0m	8033155. 790	538806. 921	-17° 47' 19. 25"	177° 21' 58. 11"
29	SL5-2m	8033139. 856	538733. 817	-17° 47' 19. 78"	177° 21' 55. 63"
30	SL5-7m	8033193. 995	537466. 619	-17° 47' 18. 09"	177° 21' 12. 59"
31	SL18-0m	8029056. 583	537984. 431	-17° 49' 32. 69"	177° 21' 30. 44"
32	SL18-2m	8029122. 891	537760. 977	-17° 49' 30. 55"	177° 21' 22. 85"
33	SL18-7m	8029465. 889	536649. 689	-17° 49' 19. 45"	177° 20' 45. 07"
34	SL22-0m	8027153. 665	537096. 103	-17° 50' 34. 66"	177° 21' 00. 39"
35	SL22-2m	8028096. 156	536355. 729	-17° 50' 04. 04"	177° 20' 35. 17"
36	SL22-7m	8028600. 762	535928. 437	-17° 49' 47. 65"	177° 20' 20. 62"
37	SL25-0m	8026666. 406	535570. 049	-17° 50' 50. 61"	177° 20' 08. 57"
38	SL25-2m	8027102. 857	535230. 818	-17° 50' 36. 43"	177° 19' 57. 01"
39	SL25-7m	8027515. 740	534917. 544	-17° 50' 23. 01"	177° 19' 46. 35"
-	NL3-0m	-	-	-	-
40	NL3-2m	8038484. 016	544768. 224	-17° 44' 25. 47"	177° 25' 20. 18"
41	NL3-7m	8038111. 905	544185. 853	-17° 44' 37. 62"	177° 25' 00. 44"
42	NL7-0m	8037008. 401	546057. 870	-17° 45' 13. 39"	177° 26' 04. 09"
43	NL7-2m	8037019. 674	545654. 429	-17° 45' 13. 05"	177° 25' 50. 39"
44	NL7-5m	8037004. 849	544917. 903	-17° 45' 13. 59"	177° 25' 25. 38"
45	NL10-0m	8035718. 324	545165. 469	-17° 45' 55. 43"	177° 25' 33. 89"
46	NL10-2m	8035774. 801	545112. 734	-17° 45' 53. 60"	177° 25' 32. 09"
47	NL10-5m	8036446. 500	544583. 465	-17° 45' 31. 78"	177° 25' 14. 06"
48	NL13-0m	8034988. 560	543763. 335	-17° 46' 19. 28"	177° 24' 46. 32"
49	NL13-2m	8035319. 797	543768. 902	-17° 46' 08. 50"	177° 24' 46. 49"
50	NL13-5m	8035925. 398	543755. 213	-17° 45' 48. 80"	177° 24' 45. 98"
-	NL17-0m	-	-	-	-
51	NL17-2m	8035963. 013	541770. 257	-17° 45' 47. 71"	177° 23' 38. 56"
52	NL17-7m	8036870. 609	541755. 707	-17° 45' 18. 18"	177° 23' 38. 00"

Figure 10-2 Implementation Plan for Surveying and Other Activities

Table 10-2 Quantities of Investigation

Survey/surveying item	Specification	Quantity	Time of implementation
[Sea coast topography]	Naisoso – Sonaisali		
Bathymetry	Control point surveying (dry season)	1 set	August 2014
	Control point surveying (rainy season)	1 set	February 2015
	L = 1,000m × 500m interval	34 surveying lines	August 2014
	L = 2,000m × 250m interval	9 surveying lines	As above
	Longitudinal section (reference quantity of 2.6km)	1 surveying line	As above
	Tide observation	1 set	August 2014 – March 2015
Sea coast line surveying	250m intervals in the transverse direction (dry season)	77 surveying lines	August 2014
	250m intervals in the transverse direction (rainy season)	77 surveying lines	March 2015
[Characteristics of drift sand and sediments]			
Observation of wave and currents	Observation of waves(dry season)	3 locations	August 2014
	Observation of tidal currents (dry season)	6 locations	August 2014
	Observation of waves (rainy season)	3 locations	March 2015
	Observation of tidal currents (rainy season)	6 locations	March 2015
Sediment survey	Sieve analysis	8 points	August 2014
	Density analysis	8 points	August 2014
	Water content analysis	8 points	August 2014
	Analysis of loss on ignition	8 points	August 2014
	Analysis of LL/PL	8 points	August 2014
Observation of the sand drift	Bed load samplers (dry season)	6 points	August 2014
	Bed load samplers (rainy season)	6 points	March 2015
Surveying type	Implemented in August 2014	Implemented in March 2015	Reference quantity of implementation
Bathymetry	55.9km	0.0km	55.9km (including supplementary survey)
Shoreline surveying	4.6km	5.3km	9.9km (including supplementary survey)

Table 10-3 List of Major Instruments

Instrument	Specification	Quantity	Implemented period
[Control point and Sea coast line survey]			
Differential GPS (DGPS)	Hemisphere Crescent A100, at the control station	1 unit	August 2014 and February and March 2015
RTK-GPS	Leica SR-530, dual frequencies, at the mobile stations	1 unit	August 2014 and February and March 2015
Handheld GPS receiver	Product of GARMIN	2 units	August 2014 and February and March 2015
[Bathymetry]			
Precision echo sounder	PDR-1300, Senbon Denki	1 unit	August 2014
Bathymetry system	GPMate-ECHO	1 unit	August 2014
Survey vessel	Made of aluminum, GW 1.9t, 150 ps class	1 unit	August 2014
[Observation of marine phenomena]			
Multifunctional oceanographic observation device (wave height and direction)	DL-3, Sonic Corporation Observation interval: 20/60 minutes	3 units	August 2014 and February and March 2015
Electromagnetic current meter	Compact-EM, JFE ALEC Observation interval: 60 seconds/20 minutes	6 units	August 2014 and February and March 2015
Survey vessel	Made of aluminum, GW 1.9t, 150 ps class	1 unit	August 2014 and February and March 2015
[Sediment survey]			
Bedload sampler	Made of steel φ6.05cm (inner diameter 5.75cm) × L 26cm	6 units	August 2014 and February and March 2015

[Explanation of terms]

Differential GPS (DGPS)

A technology to improve the accuracy of GPS (Global Positioning System) observation results by making correction of errors with the use of VHF radio wave transmitted from a base station at a known position: The base station is positioned with the GPS to elucidate the difference between the actual position and the position calculated from the GPS-based surveying. The data of this difference is transmitted from the base station on a terrestrial radio wave in the medium wave or VHF band. The data transmitted from the base stations are used at a receiver station to correct the position data measured with the signals from GPS satellites at the receiving station. While the ordinary surveying with GPS gives an error of approx. 100m, this error is reduced to approx. 5m with the use of DGPS. The word "differential" means that observed data are corrected with differential data.

i) Install a GPS receiver in a stationary state at a location whose coordinates have been determined (called "a known point"). (This receiver is called a "fixed station", "reference station" or "master station".)

ii) Conduct the GPS positioning at the known point and calculate the coordinates of the point from the positioning results.

iii) Calculate the difference between the calculated coordinates and the correct coordinates.

iv) Transmit the calculated difference on a radio wave.

v) Take another GPS receiver to a location to be positioned (a new point). (It is not necessary for *this receiver to be stationary. This receiver is called a "mobile station" or "slave station".)*

vi) Conduct the GPS positioning at the new point and obtain the coordinates.

vii) Receive the data of the difference transmitted from the known point mentioned above.

viii) Calculate more accurate coordinates by correcting the coordinates obtained from the GPS positioning with the data of the difference.

The coordinate values obtained as mentioned above are supposed to be at approx. 1m (within 2m) from the correct coordinate values.

Real-Time Kinematic GPS (RTK-GPS)

The word, "kinematic", means moving.

i) Establish a fixed GPS station and begin receiving GPS data and transmitting correction data.

ii) Set up a mobile GPS station and confirm the reception of the GPS and correction data.

iii) It is not necessary for the mobile station to be stationary. Begin the positioning when the initialization has been completed (FIX). (Coordinate data may be saved if necessary.)

iv) Remove the instruments when the positioning has been completed.

Calculate the distance to an arbitrary GPS satellite accurately by comparing the data received at the fixed station and the mobile station. As the wave length of the radio wave used in GPS is slightly shorter than 20cm, the distance can be obtained to approx. 20cm by counting the numbers of the waves. A further analysis of the phase of the waves (whether they are at the high or low point), the distance can be obtained at the submillimeter level, in theory.

10.2.2 Field Investigation

The field investigation were conducted was conducted as shown below:.

- 1st 14 August to 24 August 2014, 11 days
- 2nd 19 January to 2 February 2015, 26 days
- 3rd 22 June to 23 July 2015, 32 days

10.2.3 Surveying of the Sea coast

(1) Collection of Chart and Other Reference

A chart is a source of information on the change in sea coast profile. A chart is an important reference material which was once considered as military secret. While a chart on a scale smaller than 1/300,000 used for navigating while the land in sight is called a general chart of coast, a chart on a scale smaller than 1/50,000 is called a coast chart. Isobaths to illustrate topography of seabed and types of seabed materials represented by pre-set abbreviations indicating geological features of the seabed materials and types of sediments on seabed are also described on a chart.

While water depth on a chart is usually measured from the lowest astronomical tide (LAT), elevation is usually measured from the mean sea level (MSL). The unit of water depth and elevation (m) and the datum plane are clearly described on a chart. A position on a chart is presented with its coordinates on the World Geodetic System (WGS) 84.

This project aims at the standardization of the coordinates including the elevation of the river and sea coast. It should be noted that the elevation of the river and sea coast was measured above MSL as the datum line. (See the relationships between the elevation and tidal levels shown in Figure 10-15)

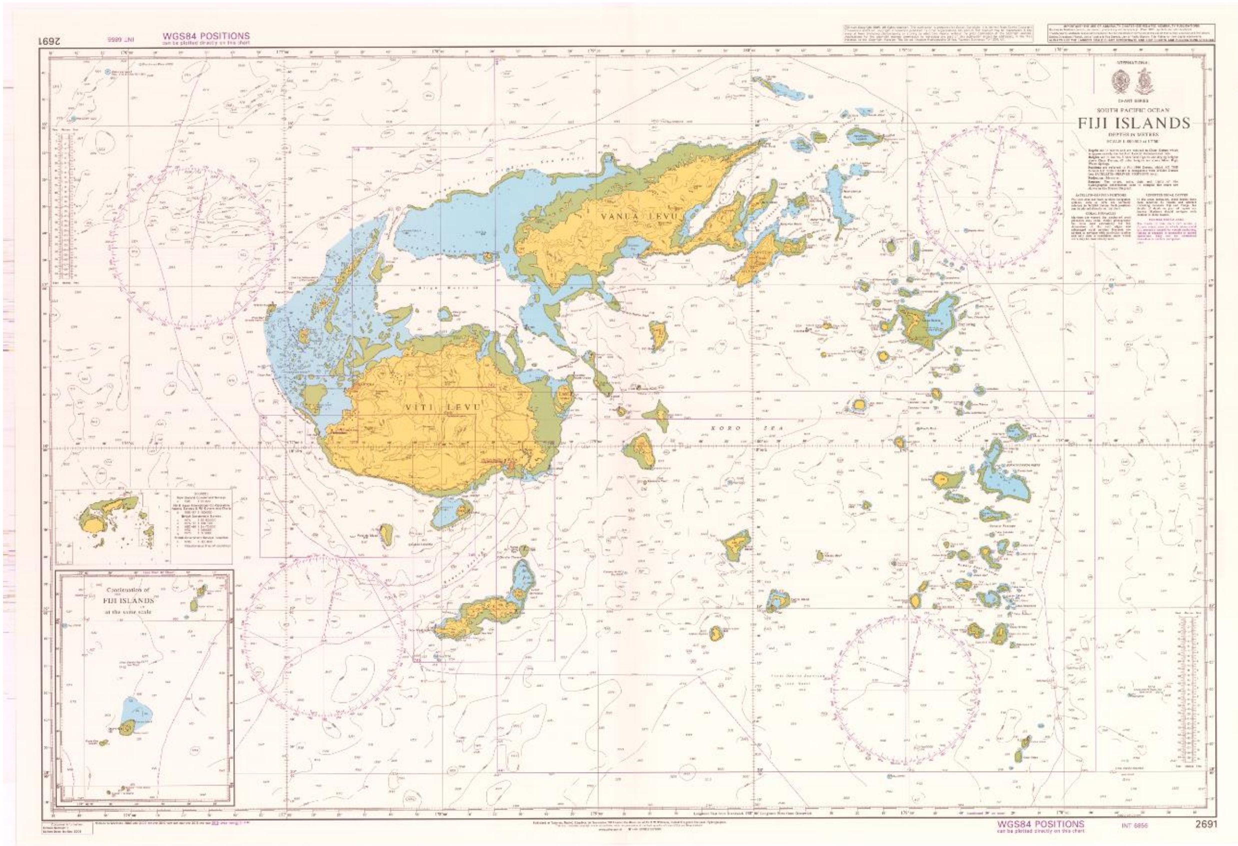


Figure 10-3 Chart (FIJI ISLANDS, WGS84-based data, 1986)

Figure 10-4 Chart (PLANS in VITI LEVU, WGS84-based data, 1942 – 1986)

1) Fiji Map Grid (FMG)

The coordinate reference system is managed with WGS84 in the Republic of Fiji. The WGS84 ellipsoid used for sea areas and in GPS is based on GRS80 used for the land area in the past. A triangulation network of control points managed by the government is being developed with the implementation of the total station (TS) surveying in the country. Although there is no GPS-based control station managed by the government in the Republic of Fiji at present, the government is planning to install them at three locations.

The “EPSG Codes” are being used for the management of coordinates with GPS. The EPSG Codes are the standards to give a specific code number to a set of parameters (including the coordinate reference system, geodetic reference system, prime meridian and map projection) required for various definitions used for presenting the surface of the three dimensional earth in two dimensions. This system is called “EPSG codes” because the sets of the parameters representing different sets of definitions are identified with different code numbers in the system. Each code contains such data as the name (e.g. JGD2000), area of use (e.g. Japan), geodetic datum (e.g. WGS), prime meridian (e.g. Greenwich meridian) and coordinate system (e.g. latitude/longitude). In the Fiji Map Grid (FMG) managed with “EPSG projection 3460 - Fiji 1986 / Fiji map grid”, a local coordinate system with the datum at 178º45’00” and 17º00’00” is used in “Zone 1.” Therefore, the conversion of horizontal coordinates in this zone to UTM (Universal Transverse Mercator) coordinates requires two conversion procedures, one to convert the horizontal coordinates to latitude/longitude and another to convert the latitude/longitude to UTM coordinates. The UTM coordinate system divides the earth in 60 zones along the meridians at the intervals of 6º and Fiji is in the Zone 60 in the world geodetic system.

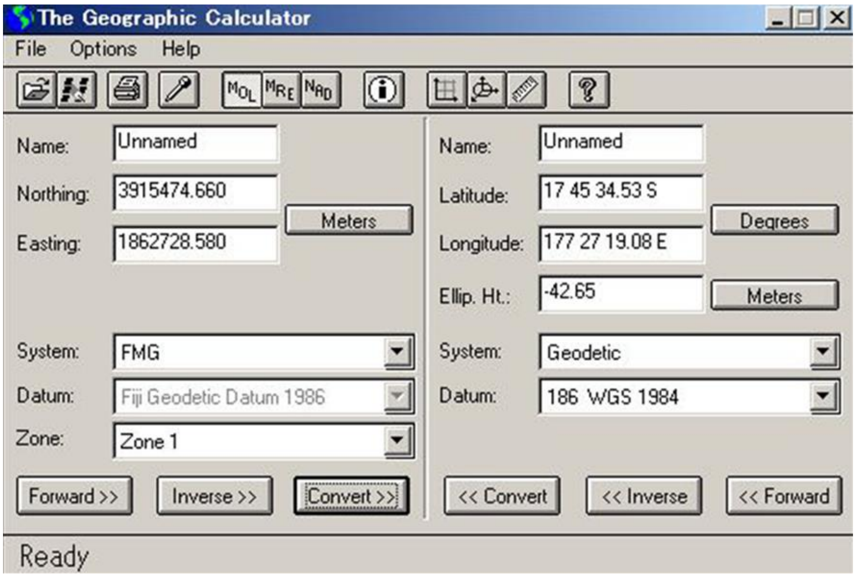


Figure 10-5 Example of Display of Coordinate Conversion Software (from FMG to latitude/longitude)

2) National Control Points

In sea coast topographical survey, the locations of the installed national control points and their coordinate values (coordinate system, XY coordinate values and elevation) were obtained from the manager of the points and the accuracy of the locations of control points were verified in the field reconnaissance before the surveying of the sea coast. Then the accuracy of the surveying of the main control points, SS3506 and SS11233, to be used in the surveys on the sea coast and river, respectively, were verified.

Figure 10-6 Control Point in Lautoka

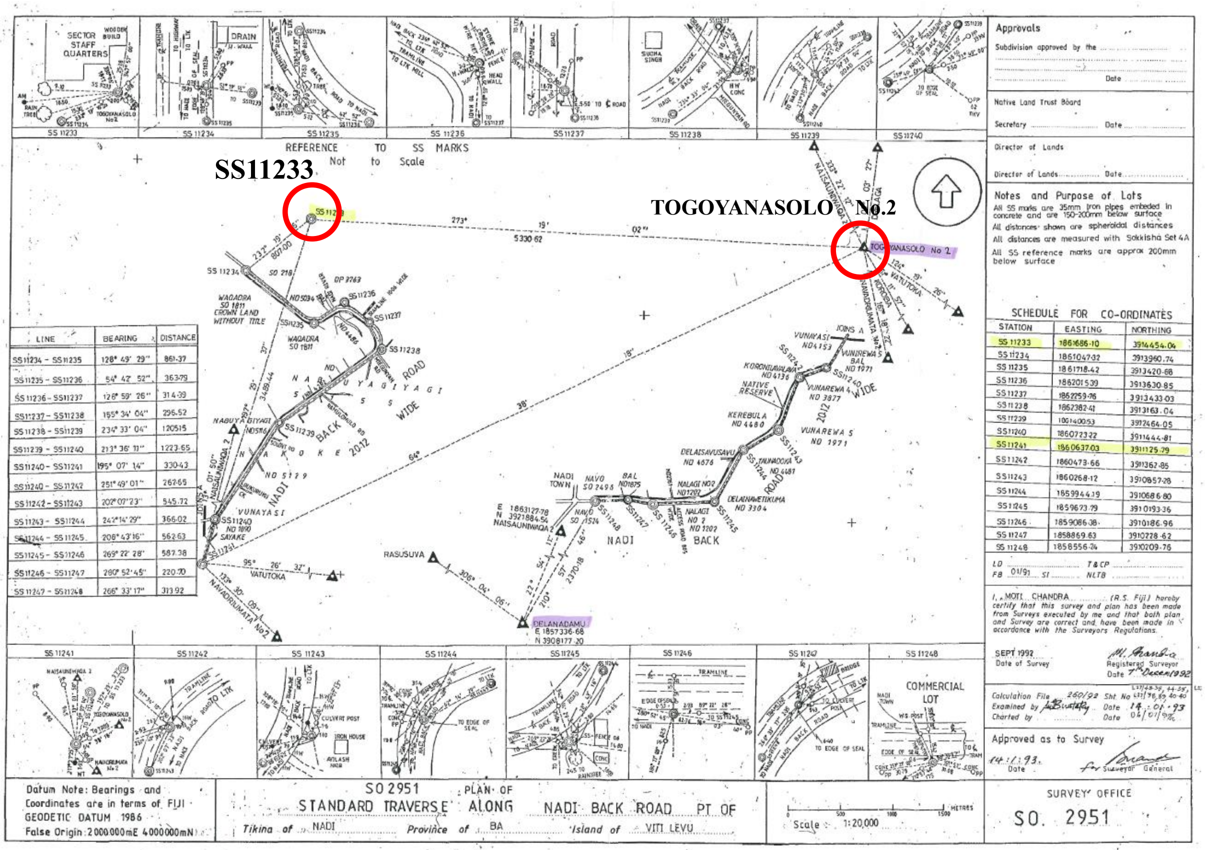


Figure 10-7 **Triangulation Network of National Control Points (including SS11233)**

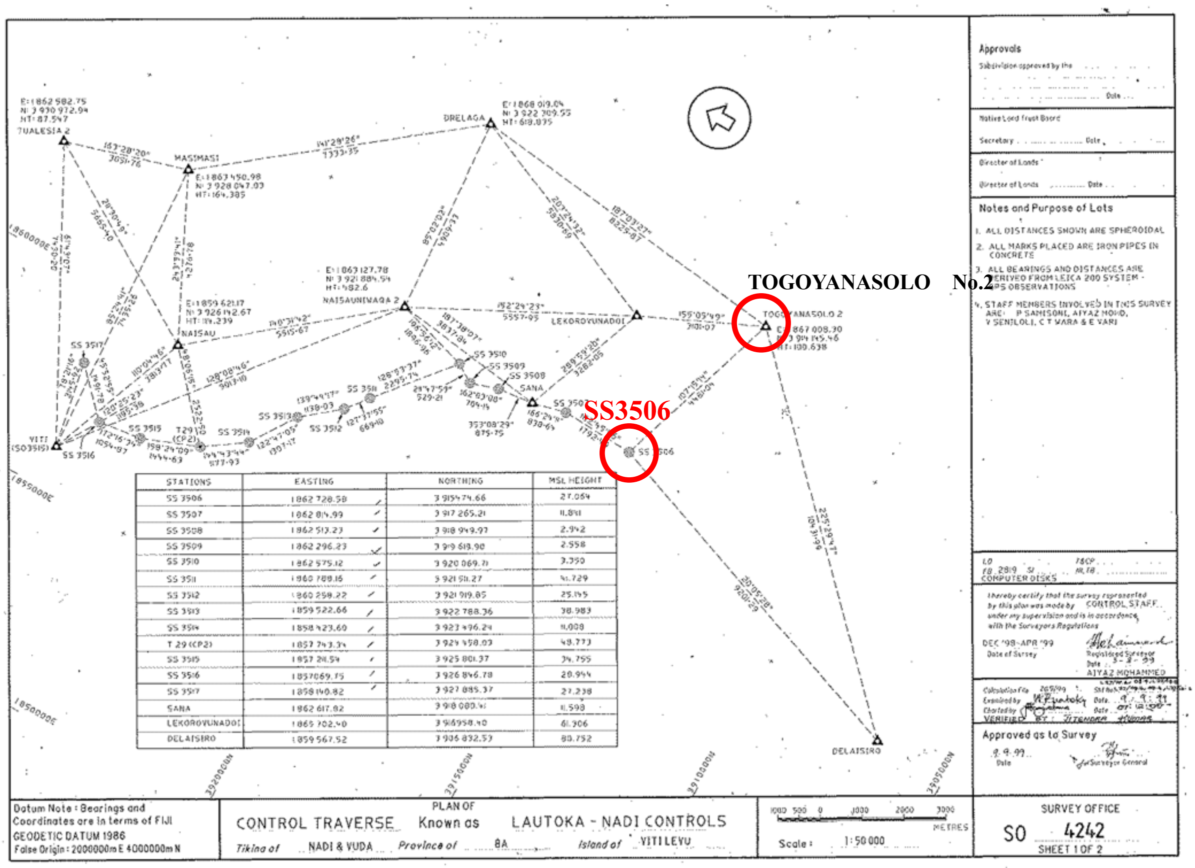


Figure 10-8 Triangulation Network of National Control Points (including SS3506)

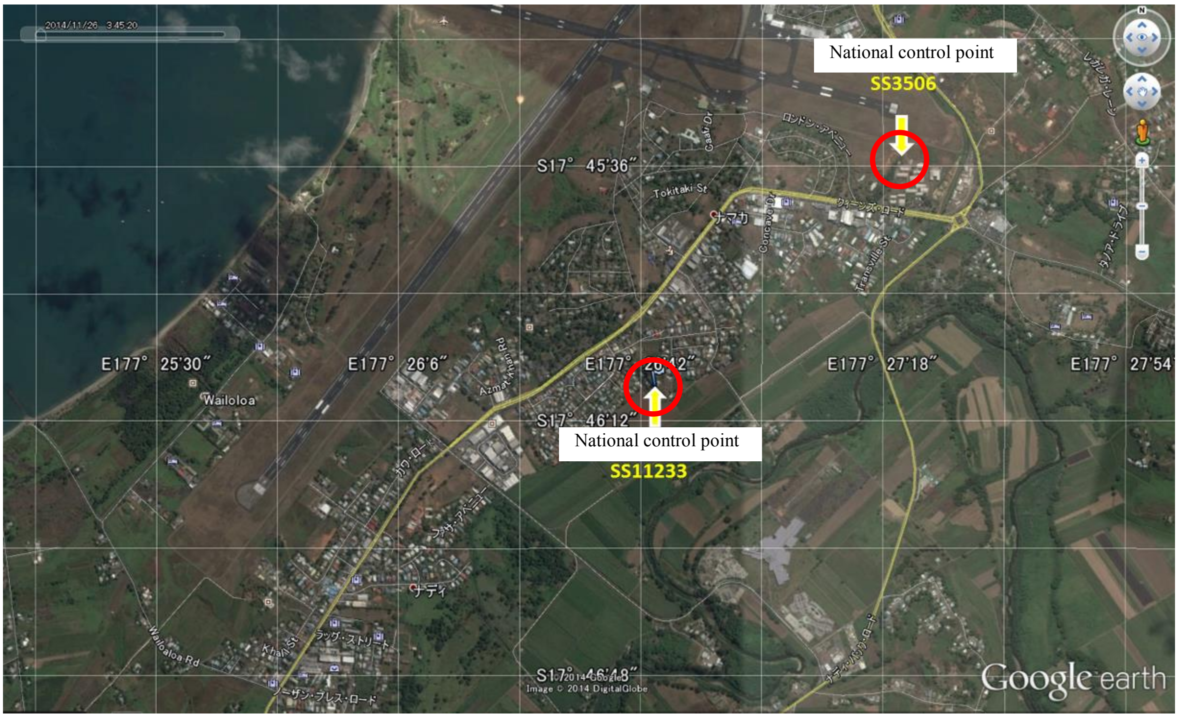


Figure 10-9 Locations of Main Control Points

New triangulation networks with national control points were created for the examination of the accuracy. The new networks were used for the calculation of the errors of closure and the calculated errors were confirmed to be below the allowable limits. Then each of the two above-mentioned control points was surveyed from the other and the errors in locations and elevation were confirmed to be below the allowable limits. These observations justified the use of these control points in this survey.

Table 10-4 confirmed that the error is below the allowable limits by calculating the triangle network of SS11233, TOGOYANASOLO No.2, SS3506 and SS11233, SS11241, SS3506.

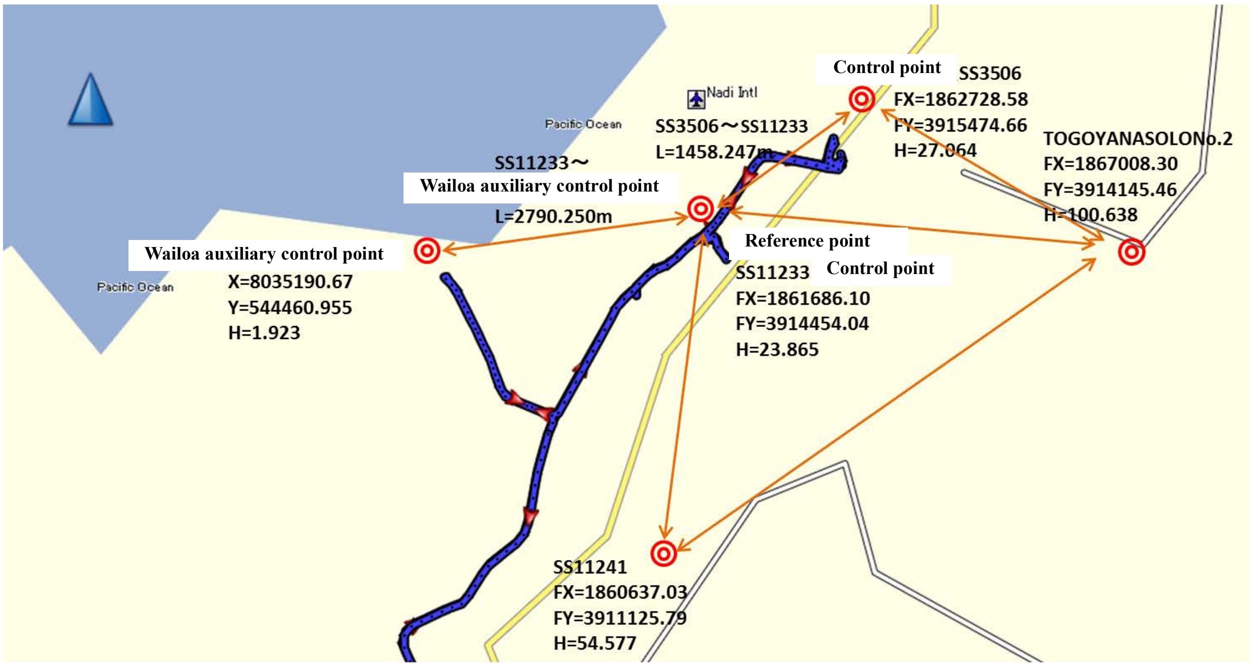


Figure 10-10 Creation of Triangulation Networks

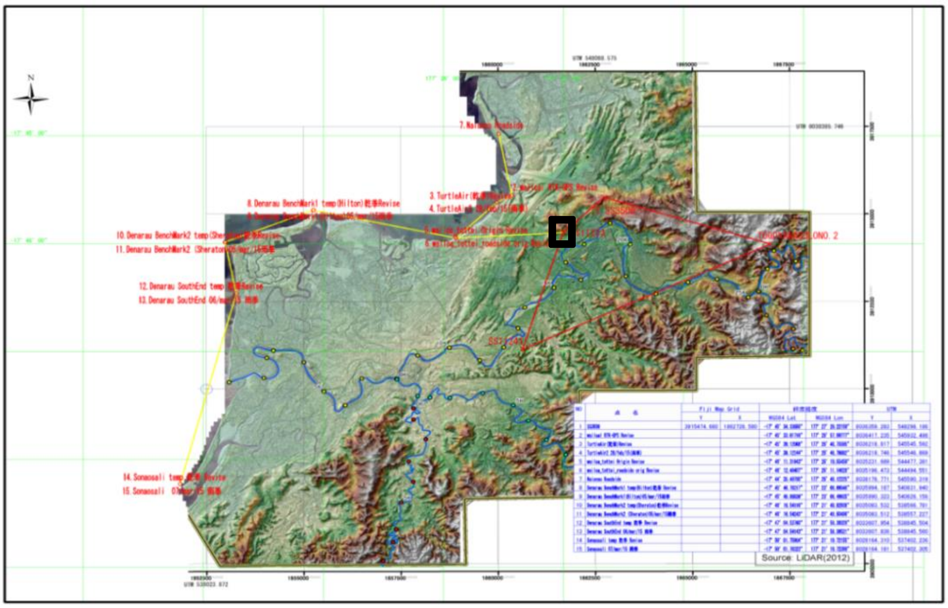
Table 10-4 Triangulation Networks and Calculation Results

No.	Fiji Map Grid Local coordinates North (Y)	Fiji Map Grid Local coordinates East (X)	Azimuth in radian	Distance between the two points	Calculation result Local coordinates North (Y)	Calculation result Local coordinates East (X)	Included angle	Elevation	Remarks
SS11233	3914454.040	1861686.100					91.314162	23.865	
	308.580	-5322.200	4.770285426	5330.62					
TOGOYANOSOLO No.2	3914145.460	1867008.300					15.211321	100.638	
	-1329.200	4279.720	1.26965985	4481.38	3915474.663	1862728.582			
SS3506	3915474.660	1862728.580					73.474517	27.064	
	1020.620	1042.480	0.795993472	1458.91	3915474.657	1862728.577			
SS11233	3914454.040	1861686.100						23.865	
	3328.250	1049.070	3.446913764	3489.44					
SS11241	3911125.790	1860637.030					47.144722		
	-3019.670	-6371.270	1.128151734	7050.64	3914145.795	1867008.144			
TOGOYANOSOLO No.2	3914145.460	1867008.300					28.678889	100.638	
	-308.580	5322.200	4.770285426	5330.62	3914145.588	1867007.788			
SS11233	3914454.040	1861686.100					104.176389	23.865	

Record of the Contorl Point

POINT NUMBER	SS11233		CONFIRMATION	TAMOTU SIBATUZI	
TYPE	metal pin		CONFIRMATION DATE	26-Jan-15	
SITE	on the ground				
COODINATE	X= 547246.719	LATITUDE	-17.7686939	FMG X	1861686.100
	Y= 8035348.886	LONGITUDE	177.4457211	FMG Y	3914454.040
	Z= 23.865	ELEVATION			

LOCATION



PHOTOGRAPH

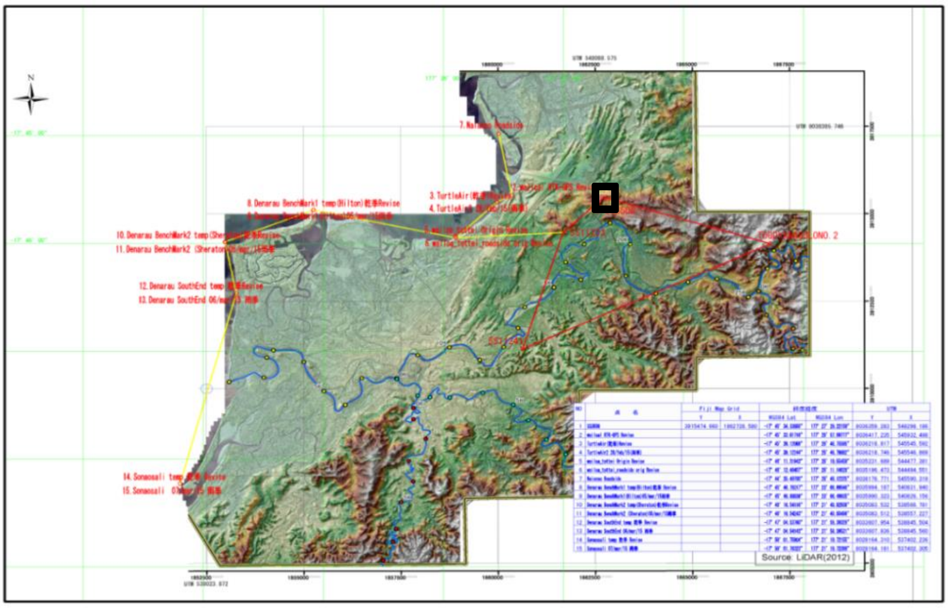
DISTANT VIEW

CLOSE VIEW

Record of the Contorl Point

POINT NUMBER	SS3506		CONFIRMATION	TAMOTU SIBATUZI	
TYPE	metal pin		CONFIRMATION DATE	19-Aug-14	
SITE	on the ground				
COODINATE	X= 548298.186	LATITUDE	-17.75953847	FMG X	1862728.58
	Y= 8036359.283	LONGITUDE	177.4556171	FMG Y:	3915474.66
	Z= 27.064	ELEVATION			

LOCATION



PHOTOGRAPH

DISTANT VIEW	CLOSE VIEW
	

Each of the two national control points, SS11233 and SS3506, was surveyed using RTK-GPS (Table 10-5). The errors in this GPS surveying were proven to be below the allowable limits.

Table 10-5 Coordinate Values and Results of GPS Two-way Surveying of Main Control Points

No.	Fiji Map Grid Local coordinates North (Y)	Fiji Map Grid Local coordinates East (X)	WGS84 Lat dmmss.sss	WGS84 Lon dmmss.sss	UTM coordinates South (Y)	UTM coordinates East (X)	Ellipsoidal height	Elevation	Remarks
SS3506 (FNU), national control point: coordinates in the reference	3915474.660	1862728.580	−17° 45' 34.3390"	177° 27' 20.2220"	8036359.268	548298.201	84.777	27.064	
2) SS3506 (FNU), coordinates obtained in the surveying from the control station at SS11233			−17° 45' 34.3388"	177° 27' 20.2186"	8036359.276	548298.101	84.804	27.091	
dif.					−0.008	0.100	−84.804	−0.027	
SS11233, national control point: coordinates in the reference	3914454.040	1861686.100	−17° 46' 07.2980"	177° 26' 44.5960"	8035348.886	547246.719	81.572	23.865	
2) SS11233, coordinates obtained in the surveying from the control station at SS3506 1st			−17° 46' 07.2979"	177° 26' 44.5989"	8035348.883	547246.816	81.550	23.843	
dif.					0.003	−0.097	−81.550	0.022	

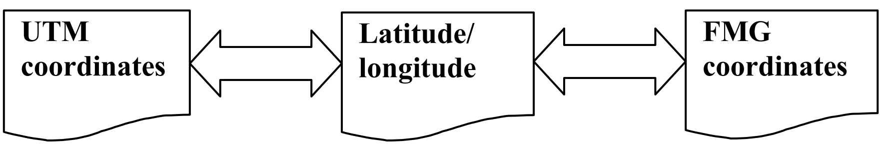
An auxiliary control point required for the bathymetry and shoreline surveying was installed by driving a surveying nail in the pavement on the rock jetty in Wailoaloa near the shoreline. (See Attachment, "Description of the Control Points"). An open traverse created with this point as the origin and auxiliary control points installed at the points on the traverse were used in the surveying conducted in August 2014 and February – March 2015.

The table below shows the allowable limits for the three-dimensional network adjustment in GNSS observation with a GNSS surveying instrument fixed at a known point in the Surveying Work Rules established in accordance with provisions of the Article 33 (1) of the Survey Act in Japan. These limits were used in this survey.

Table 10-6 Allowable Limits of GNSS Surveying

Classification / Item	Primary control point surveying	Secondary control point surveying	Tertiary control point surveying	Quaternary control point surveying
Residual of each component of the baseline vector	20mm	20mm	20mm	20mm
Horizontal error of closure	Δs = 100mm + 40mm√N Δs: Difference in the distances obtained from the result of the surveying of the known point and the result of the hypothetical three-dimensional network adjustment N: Minimum number of sides on the traverse to the known point (If there is more than one traverse with the same minimum number of sides, use the number on the shortest traverse.)			
Vertical error of closure	Use 250mm + 45mm √N, where N is the number of sides, as the standard			

As the coordinates of locations in the Republic of Fiji are managed with a local coordinate system, FMG (Fiji Map Grid), centered at the datum moved from the datum of the WGS Zone 60 to 178º45'00"E and 17 º00'00"S, coordinates obtained in the surveying have to be converted to appropriate coordinates. This conversion from the local to global system is performed by using software for coordinate conversion available on the Internet through the intermediate of the latitude/longitude coordinates.



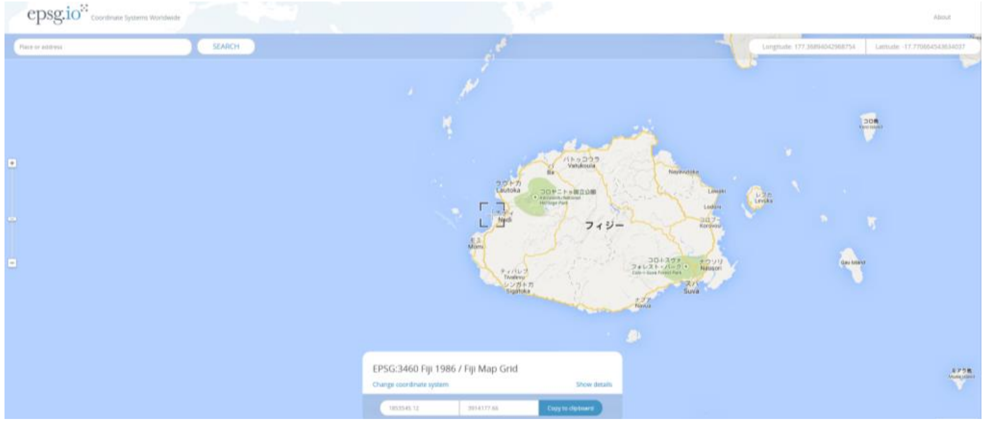


Figure 10-11 Software for the Conversion between the Latitude/Longitude and FMG Coordinates

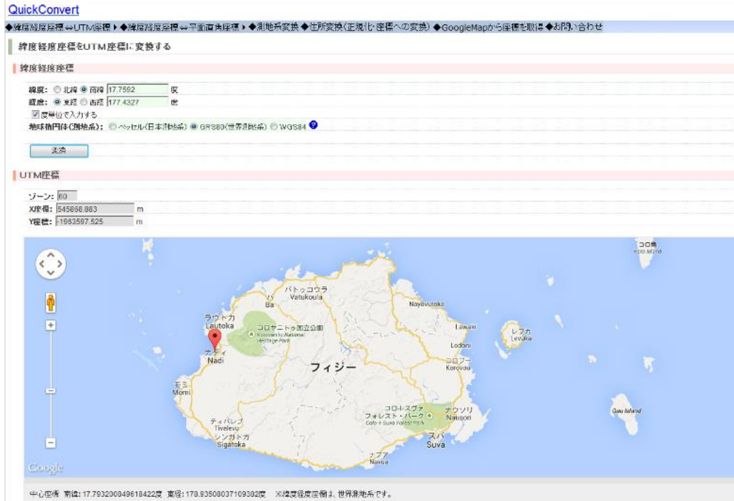


Figure 10-12 Software for the Conversion between the Latitude/Longitude and UTM Coordinates

In the UTM projection, the datum is located at the intersection between the central meridian and the equator and the coordinate values increase as a location goes north and east.

In this system, a location west of the central meridian or in the southern hemisphere has a negative coordinate value. As the calculation with both positive and negative values is prone to errors, 500,000m is to be added to the Easting (X) value of a location west of the datum and 10,000,000m is to be added to the Northing (Y) value of a location in the southern hemisphere.

As Nadi is located "east of the central meridian and in the southern hemisphere" in the UTM Zone 60, Easting (X) of the coordinates is as obtained and 10,000,000m should be added to the obtained Northing (Y) value.

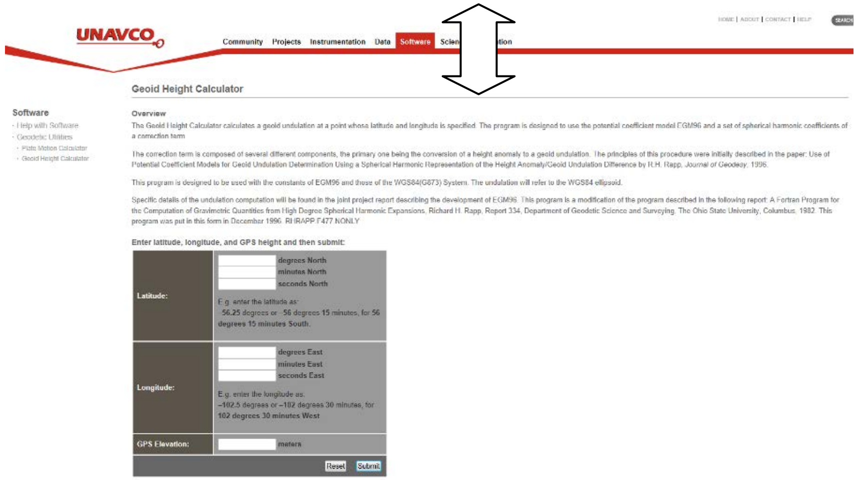


Figure 10-13 Software to Output GPS Elevation from UTM Coordinates

(2) Leveling

In accuracy control, the values in Table 10-5 have confirmed that the leveling errors in the double-way surveying of the national control points, SS11233 and SS3506, were below the allowable limits shown in Table 10-7.

These allowable limits for the quaternary leveling based on "Standards for the Quantification of the Contracted Civil Works in Ports and Harbors – 2012 Edition (April 2012, The Ports and Harbours Association of Japan)".

Table 10-7 Allowable Limits on Quaternary Leveling

Item	Quaternary leveling
Difference between the observed values in the two-way surveying	20mm√S
Error of closure	20mm√S
Error of closure between known points	25mm√S

S: Observation distance (one-way, in km)

(3) Tidal levels

The sea level in the Lautoka Port has been measured continuously since South Pacific Sea Level and Climate Monitoring Project installed automatic tide gauge of SEAFRAME(Sea level Fine Resolution Acoustic Measuring Equipment) in the port in 1973 and the measurements have been made public at all times. MSL in 1993 was determined at DL +1.1538m.

As the measurements in the bathymetry were to be rounded to the nearest 10cm, MSL of DL+1.15m at 6707-Lautoka described in Fiji Nautical Almanac (2014 edition) was used in this survey. It was decided to use MSL at the Lautoka Port as the datum level for the leveling in western Lautoka.

Therefore, it was decided to describe elevation EL to mm and to set elevation EL ± 0.000 = (MSL)DL+ 1.150 as the datum line in the final report.

The figure on the right is a schematic diagram of tidal levels in the Suva Harbor described in Fiji Nautical Almanac. Water depth and elevation of sea chart are measured from the lowest astronomical tide (L.A.T.) and MSL, respectively. There are seasonal variations in the tidal levels at high and low tides. The spring and neap ranges in the reference port of the Suva Harbor are between DL+0.4m and DL+1.8m and between +0.1m and +1.6m, respectively. MSL in this port is DL+1.1m, which is different from MSL at Lautoka at DL+1.15m because of difference of location and topography around each port.

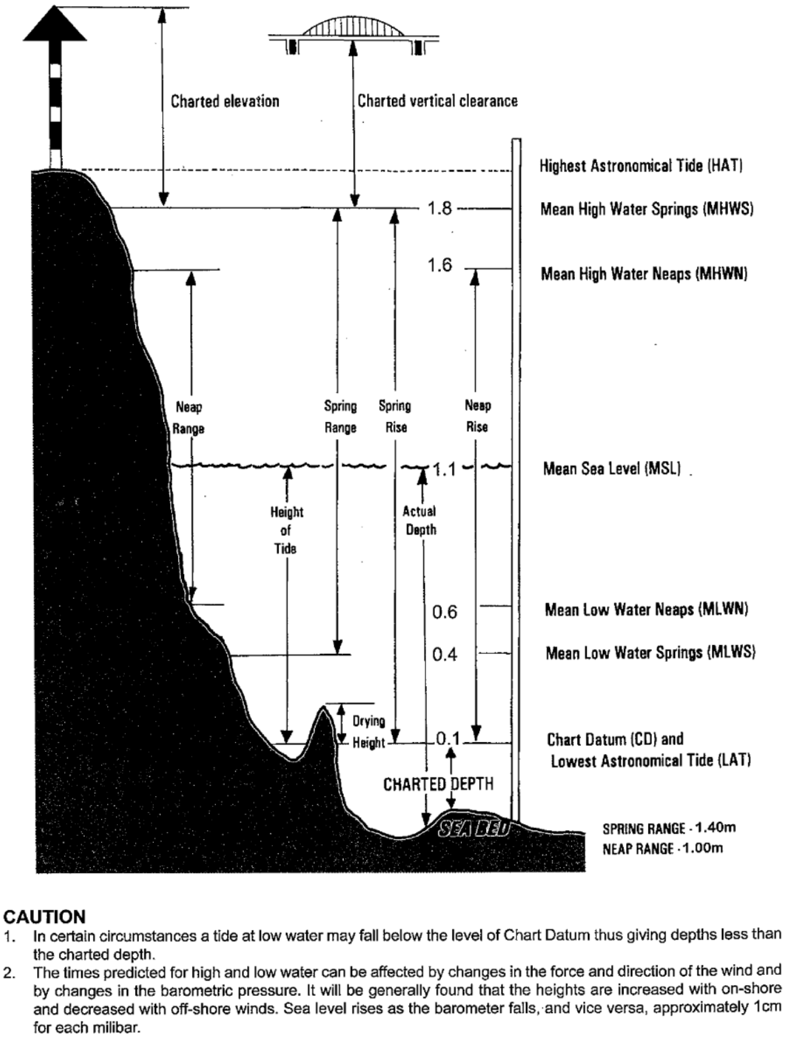


Figure 10-14 Tidal Levels and Charted Data in Suva Harbor

Figure 10-15 is a diagram showing the relationships between the tidal levels and elevation. In general, MSL is practically obtained by taking average of the sea level of long term and the mean high water level (MHWL) and mean low water level (MLWL) are the means of every high and low tides, respectively, including those at the time of spring and neap tides.

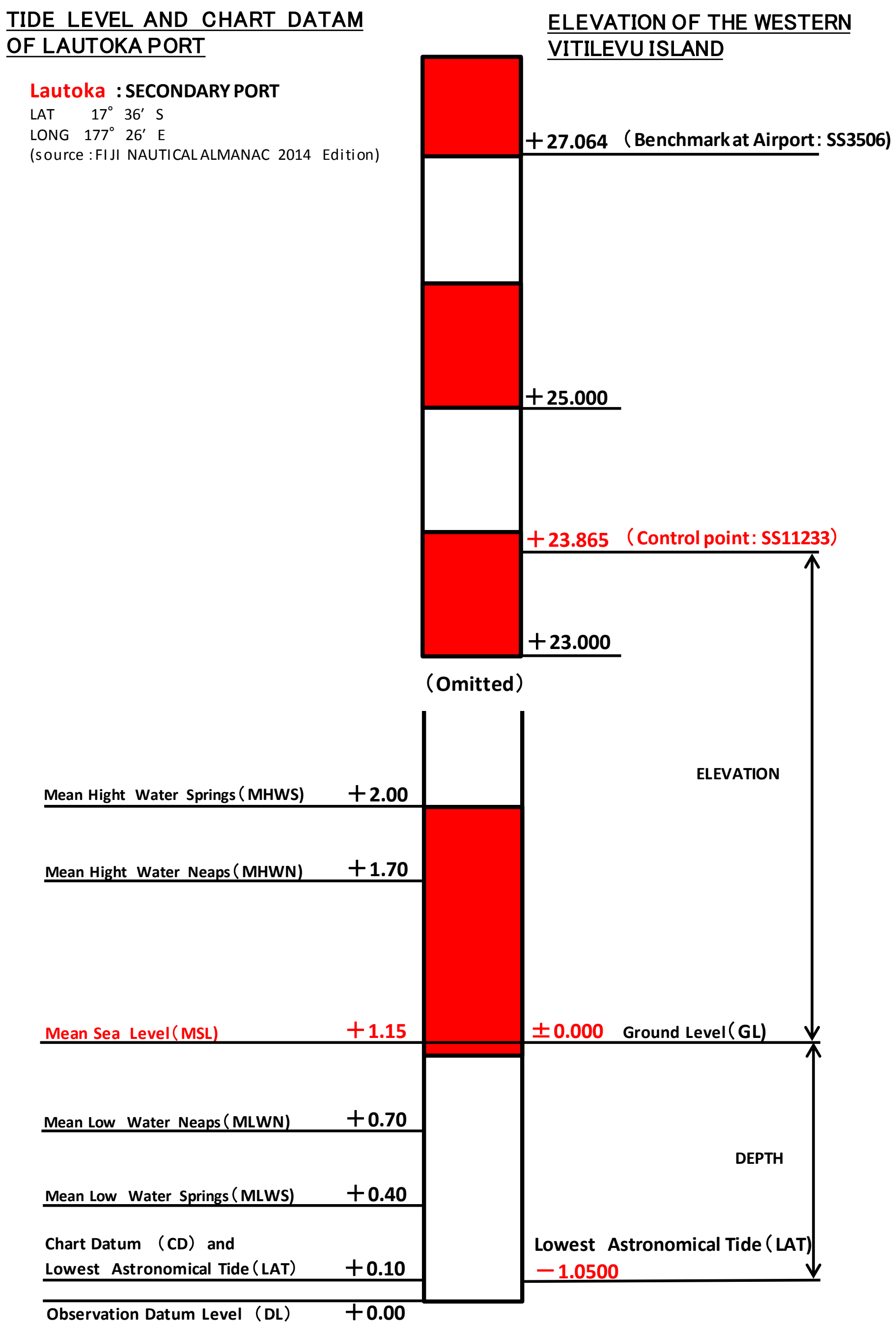


Figure 10-15 Relationship between Tidal Levels and Elevation

Sea levels are observed at two locations, one each in the Suva Harbor and the Lautoka Port, in the Republic of Fiji.

One of the photographs below (Figure 10-16) shows the appearance of the array gauge installed in the Lautoka Port (17°36′17.7″S/177°26′17.7″E) in October 1992.

Figure 10-16 Inside of Sea Level and Climate Monitoring Station in Lautoka Port

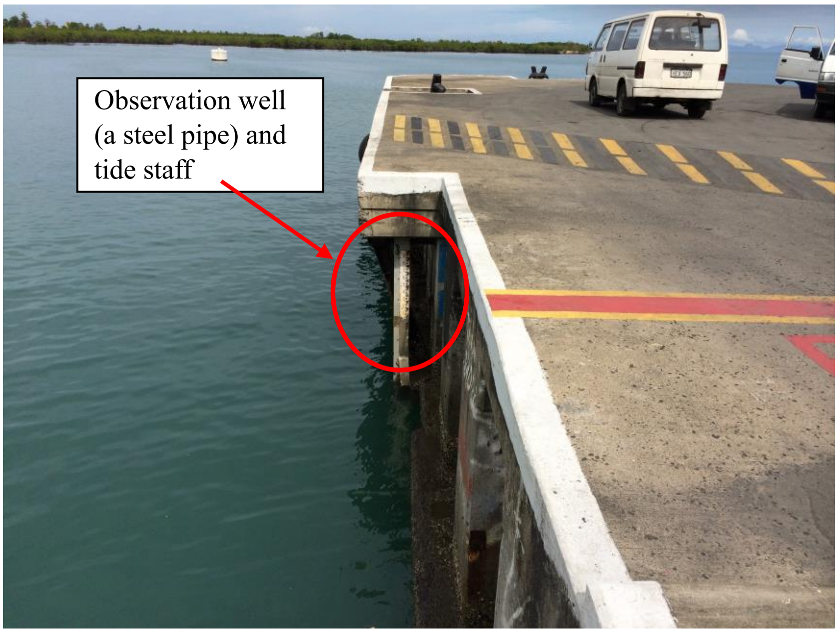


Figure 10-17 Outside of Sea Level and Climate Monitoring Station in Lautoka Port

Tides are the regular and periodic rise and fall of sea level observed as tidal changes. As waves and flood tides do not occur regularly or periodically, they are not considered as components of astronomical tides. Movements of celestial bodies such as the moon and the sun are well-known regular and periodic natural phenomena. The rise and fall of the sea level caused by the revolution of the earth, the moon and the sun and the rotation of the earth are called tides. If this rise and fall of the sea level is perceived as a vertical movement, tidal current is a periodic flow of seawater in the horizontal direction caused by the tidal sea level change. Such tidal movement is the sum of main four component tides which are caused by moon and sun, and other component tide.

(4) Bathymetry

1) Method of Bathymetry

The precision echo sounder (PDR1300 of Senbon Denki, accuracy of (±0.03mm + depth/1000m) and the RTK-GPS bathymetry system were installed on a small vessel. A one-dimensional sounding rod was also installed on the broadside of the vessel. The bathymetric measurements were taken while the vessel was moving to the shoreline at an appropriate speed along the planned surveying lines. The data of the surveying line were entered in a laptop computer in advance and used for the navigation of the vessel guided by the signal from the base station installed at the auxiliary control point. As the gradient of the seabed was shoaling in the bathymetry area, the measurements were taken one-way. Longitudinal bathymetry along the line connecting the two heads of the bay mouth was conducted in Nadi Bay to elucidate changes in the seabed topography.

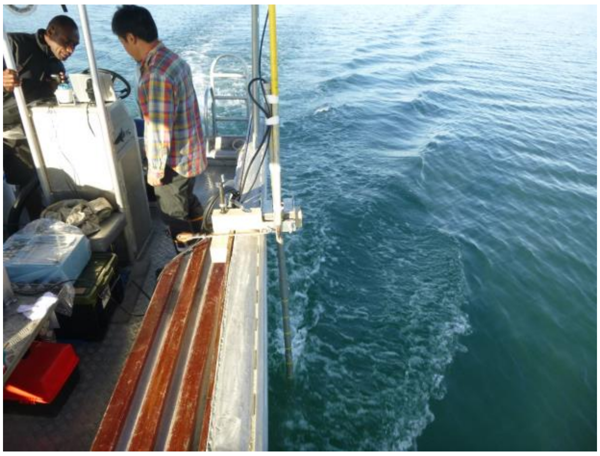


Figure 10-18 Bathymetry

2) Method for the Measurement of Tidal Level

Measurement of the tide level is required for the datum level of bathymetry. The methods to measure tidal level include the method to observe it with a tide staff installed at a location of known elevation and the method to obtain the record of the measurement of tidal level from a nearby tide monitoring station. Although the area of the bathymetry in this study is near the sea level monitoring station in the Lautoka Port (managed by SOPAC) where the sea level is measured and recorded, the record cannot be available in real-time because the data are transmitted directly to Australia. In this study the change in the tidal level has been monitored during the survey period with a water level gauge (U20 Water Level Logger for saltwater deployment, refer to Figure 10-20) installed in the Port of Denarau, though not as a simple tide station. However, there was some concern over the reliability of the data taken with this gauge installed between the mooring pier and the fueling pier as instructed by the port manager, because the sea near this site was heavily used by small vessels and this site was located near the estuary of a branch of the Nadi River (refer to Figure 10-21 and Figure 10-22). Because of this concern, the tidal level at the time of the observation was adjusted using the publicly available data of the astronomical tide. It is known that topography of the land and seabed affect tidal level. The parameters for correction of tidal level with the reference in the Suva Harbor for the major ports in the Republic of Fiji are described in "Fiji Nautical Almanac". The almanac gives a time correction of -5 minutes and a tidal level (amplitude) correction of the maximum of +20cm for the Lautoka Port in comparison with the Suva Harbor, though the parameters change by season (refer to Figure 10-19. MSL is DL+1.1500m as shown in the chart showing the relationships between the tidal levels and elevation in Figure 10-15. The recording of tidal levels in the Republic of Fiji began in 1973. Therefore, the tidal levels have been measured for more than 40 years. As the astronomical tide obtained from the records which have been kept for such a long time should be highly reliable, it was chosen as the reference of the tidal level.

PART II
TIME AND HEIGHT DIFFERENCES
FOR PREDICTING THE TIDES AT
SECONDARY PORTS

No	PLACE	Lat	Long	TIME DIFFERENCES MHW	MLW	HEIGHT DIFFERENCES (IN METRES) MHWS	MHWN	MLWN	MLWS	M.L. Zo m.	
	Viti Levu	S	E								
6705	SUVA HARBOUR	18 08	178 26	STANDARD PORT		**1.8**	**1.6**	**0.6**	**0.4**	1.10	
6706	Rukua	18 23	178 08	+0020	+0020	-0.1	0.0	+0.1	+0.2	1.14	a
6707	Lautoka	17 36	177 26	-0005	-0006	+0.2	+0.1	+0.1	0.0	1.15	
6707a	Vuda Point	17 41	177 23	-0005	-0005	-0.1	-0.1	-0.2	-0.2	0.97	a
	Yasawa Island										
6708	Manuqila Bay	16 42	177 36	-0025	-0025	-0.2	-0.3	0.0	-0.2	0.93	
6708a	Nabukeru	16 51	177 28	-0025	-0025	-0.1	-0.3	-0.1	-0.2	0.94	
	Viti Levu										
6708b	Vatia Wharf	17 24	177 46	-0015	-0020	+0.2	+0.1	+0.1	0.0	1.24	
6709	Manava Cay	17 21	177 49	-0020	-0020	+0.1	0.0	+0.1	0.0	1.15	
6710	Ellington Wharf	17 20	178 13	-0010	-0005	-0.1	-0.2	-0.1	-0.1	0.97	
6710a	Nanukuloa	17 27	178 14	-0005	-0010	0.0	0.0	+0.2	+0.1	1.2	x
6710b	Naigani	17 35	178 40	-0015	-0015	-0.1	-0.2	0.0	-0.1	1.02	a
6711	Tailevu	17 39	178 35	+0005	0000	-0.2	-0.3	-0.1	-0.1	0.92	
6711a	Leleuvia Island	17 48	178 43	+0035	+0035	-0.3	-0.4	-0.3	-0.3	0.80	

Figure 10-19 Tidal Level Conversion Table of Fiji

A pressure-sensor water gauge, U20 Water Level Logger Titanium for saltwater deployment (manufactured by Onset), was used for the simple measurement of the tidal level in the field. It was fixed on a concrete block and installed between the mooring pier and the fueling pier on August 29th, 2014 (the coordinates of the location of the installation: 17°46′21.3″S/177°22′53.34″E). It was retrieved on March 6th, 2015. All the data collected by the logger have been downloaded to the analysis system.

Figure 10-20 Pressure-sensor Water Gauge, U20 Water Level Logger, (left) and Gauge Tied to Concrete Block before Installation (right)

The figures below show the graphs drawn with the observed data. The cycle and amplitude of the high and low tides observed in the astronomical tide and the tide gauge data are almost identical.

The figures below show the graphs of the observed data drawn with the astronomical tide data. The cycle and amplitude of the high and low tides observed in the astronomical tide and the tide gauge data are almost identical.

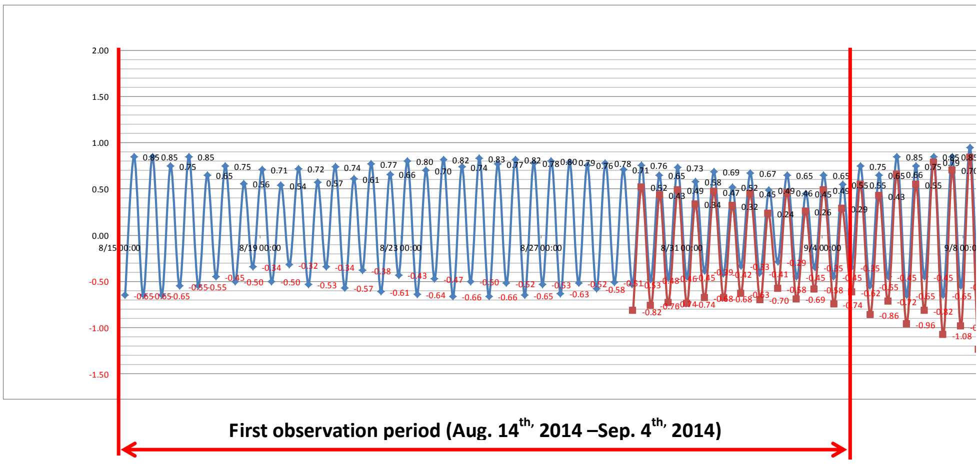


Figure 10-21 Tidal Level in Period in which Oceanographic Observation Instruments were Installed in August and September 2014

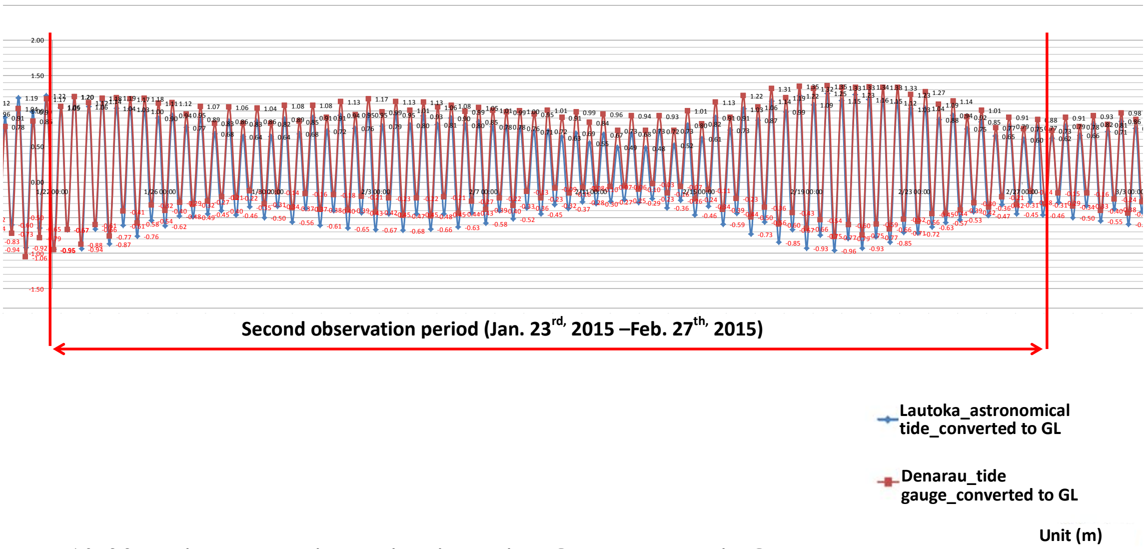
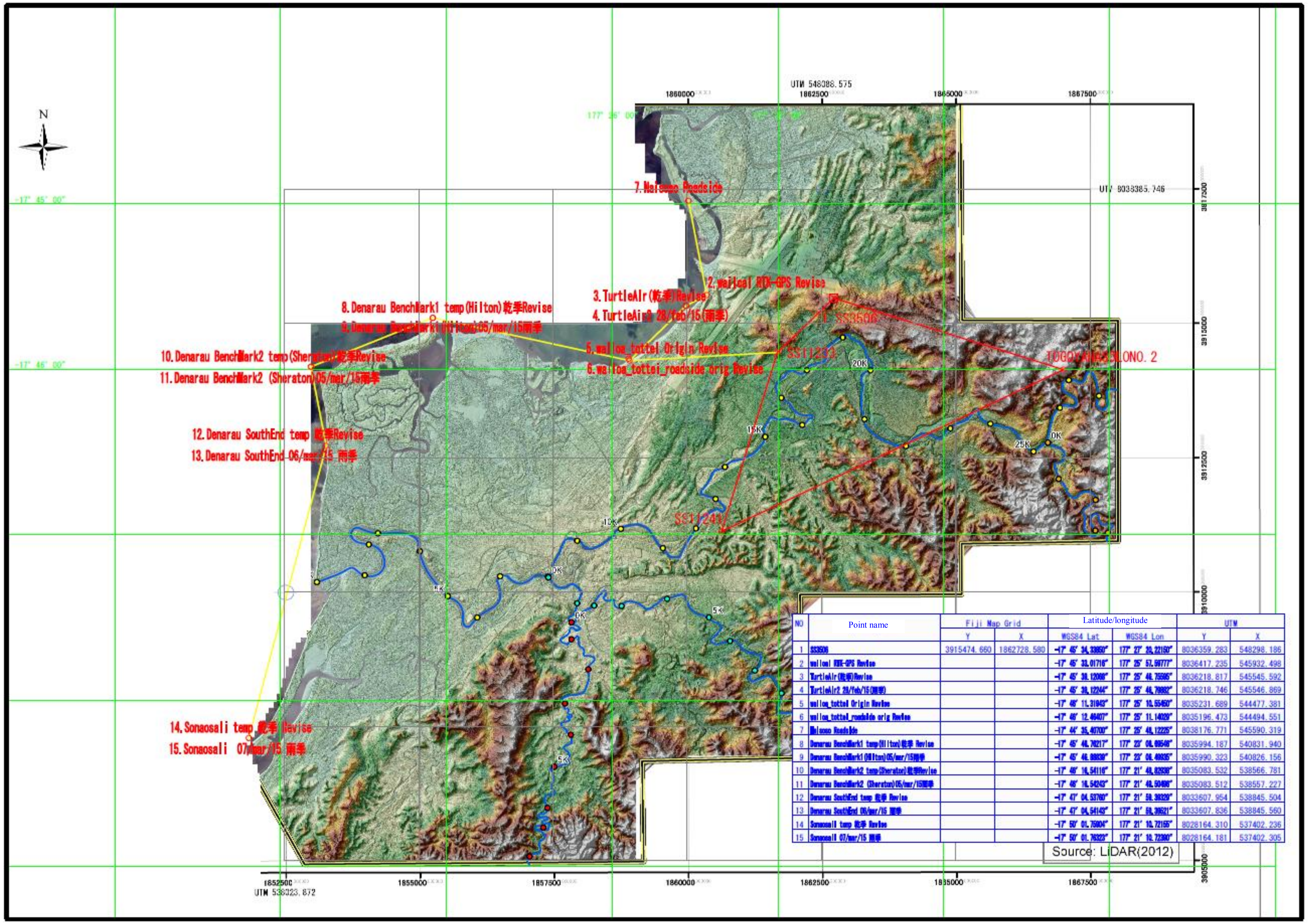


Figure 10-22 Tidal Level in Period in which Oceanographic Observation Instruments were Installed in January and February 2015

(5) Shoreline surveying

The shoreline was surveyed with a base station installed at the auxiliary points established from the known control points/benchmarks. The surveying was conducted along each surveying line in the areas. The surveying was conducted on foot. The control station DGPS and mobile station RTK-GPS (Leica GPS SR530) were used in the surveying. The surveying was not conducted at points to which it was impossible to gain access on foot or by small vessel such as those in tidal flat-like areas with soft ground, a mangrove forest and a private lot.

Figure 10-23 Shoreline Surveying



NO	Point name	Fiji Map Grid Y	Fiji Map Grid X	Latitude/longitude WGS84 Lat	Latitude/longitude WGS84 Lon	UTM Y	UTM X
1	SS3506	3915474.660	1862728.580	-17° 45' 34.33850"	177° 27' 28.22150"	8036359.283	548298.186
2	wailoal RTK-GPS Revise			-17° 45' 33.01716"	177° 25' 57.59777"	8036417.235	545932.498
3	TurtleAir(乾季)Revise			-17° 45' 38.12068"	177° 25' 44.75595"	8036218.817	545545.592
4	TurtleAir2 28/feb/15(雨季)			-17° 45' 38.12244"	177° 25' 44.79882"	8036218.746	545546.869
5	wailoa_tottei Origin Revise			-17° 46' 11.31943"	177° 25' 10.55450"	8035231.689	544477.381
6	wailoa_tottei_roadside orig Revise			-17° 46' 12.46407"	177° 25' 11.14029"	8035196.473	544494.551
7	Naisoso Roadside			-17° 44' 35.40700"	177° 25' 48.12225"	8038176.771	545590.319
8	Denarau BenchMark1 temp(Hilton)乾季 Revise			-17° 45' 44.70217"	177° 23' 08.09548"	8035994.187	540831.940
9	Denarau BenchMark1(Hilton)05/mar/15雨季			-17° 45' 44.88838"	177° 23' 08.49935"	8035990.323	540826.156
10	Denarau BenchMark2 temp(Sheraton)乾季Revise			-17° 46' 14.54116"	177° 21' 48.82938"	8035083.532	538566.781
11	Denarau BenchMark2 (Sheraton)05/mar/15雨季			-17° 46' 14.54243"	177° 21' 48.50496"	8035083.512	538557.227
12	Denarau SouthEnd temp 乾季 Revise			-17° 47' 04.53760"	177° 21' 58.38329"	8033607.954	538845.504
13	Denarau SouthEnd 06/mar/15 雨季			-17° 47' 04.54143"	177° 21' 58.39521"	8033607.836	538845.560
14	Sonaosali temp 乾季 Revise			-17° 50' 01.75804"	177° 21' 10.72155"	8028164.310	537402.236
15	Sonaosali 07/mar/15 雨季			-17° 50' 01.76323"	177° 21' 10.72380"	8028164.181	537402.305

Figure 10-24 Control Point/Auxiliary Control Point Network Map

10.2.4 Observation of the Currents and Sediment Survey

(1) Observation of Currents

1) Observation methods

The oceanographic observation instruments (three wave meters, D-1 to D-3, and six current meters, C-1 to C-6) were installed at the locations designated in the plan. Turbulence of the sea was not expected in the first observation period because it was in the season of stable weather. Therefore, the data were obtained for 15 days and nights, the minimum period required for the data obtained to be used in the analysis. The period of observation was extended to 30 days and nights in the second observation period so that the data of the turbulent sea caused by cyclone could be obtained.

First observation period (data measurement and acquisition in 15 days and nights):
August 14th, 2014 – September 4th, 2014

Second observation period (data measurement and acquisition in 30 days and nights):
January 23rd, 2015 – February 27th, 2015

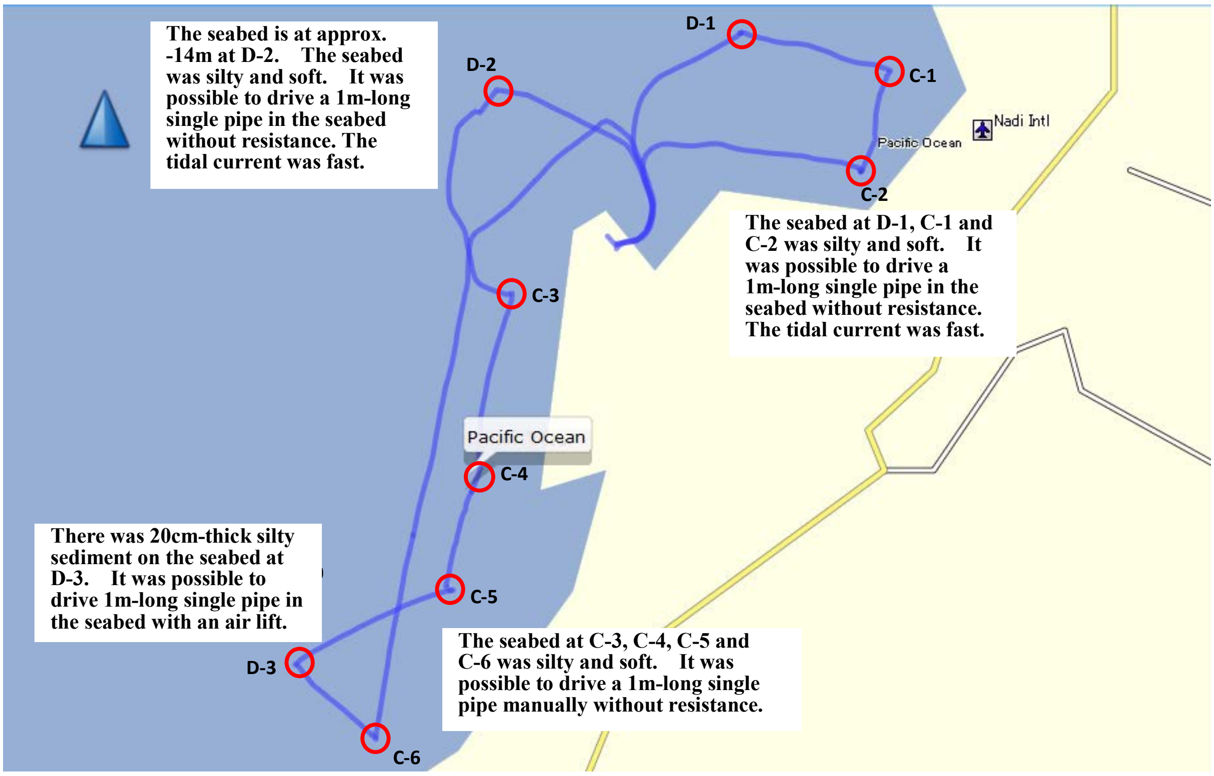


Figure 10-25 Locations of Installation of Oceanographic Observation Instruments in January 2015

Figure 10-25 shows the routes taken when the oceanographic observation instruments were installed in January 2015. A handheld GPS receiver was used to trace the routes. The instruments were installed in the order of C3, C4, C5, D3, C6 and D2 on January 23rd, 2015 and D1, C1 and C2 on January 24th, 2015. At the time of the installation and removal of the instruments, the information on the condition of the seabed was obtained from the divers. Their information revealed the existence of a spread of thick silty sediment on the seabed both in Nadi Bay and near the estuary of the Nadi River. The quantity of the sediment was larger in March 2015 than in August 2014.

Table 10-8 Installation of Oceanographic Observation Instruments (August 14th, 2014 – September 4th, 2014)

	Label	Latitude (South)			Longitude (East)			Depth	Time of bathymetry	Date and time of the completion of the installation	Date and time of the completion of the removal	
		Deg.	Min.	Sec.	Deg.	Min.	Sec.				Instruments	Bedload Sampler
DL-3	D1, in the original plan	17	44	01.36	177	24	09.01					–
	D1, location verified on 15 Aug	17	44	36.77	177	24	07.59	8.7m	2014/8/15 14:46			–
	D1, location of the installation on 16 Aug	17	44	36.40	177	24	08.10			2014/8/16 17:50	2014/9/5 7:31	–
	D2, in the original plan	17	45	15.90	177	21	07.29					–
	D2, location verified on 15 Aug	17	45	03.39	177	21	39.22	13.3m	2014/8/15 18:00			–
	D2, location of the installation on 17 Aug	17	45	04.50	177	21	40.70			2014/8/17 15:20	2014/9/3 14:31	–
	D3, in the original plan	17	49	51.14	177	19	42.75					–
	D3, location verified on 15 Aug	17	49	49.02	177	19	41.87	10.0m	2014/8/15 17:13			–
	D3, location of the installation on 18 Aug	17	49	48.70	177	19	41.90			2014/8/18 14:10	2014/9/3 12:06	–
C-EM	C1, in the original plan	17	44	51.40	177	25	49.06					
	C1, location verified on 15 Aug	17	44	54.56	177	25	38.69	2.0m	2014/8/15 15:25			
	C1, location of the installation on 16 Aug	17	44	54.80	177	25	39.00			2014/8/16 16:50	2014/9/5 8:00	2014/9/5 7:58
	C2, in the original plan	17	45	45.49	177	25	21.28					
	C2, location verified on 15 Aug	17	45	45.98	177	25	21.71	2.6m	2014/8/15 15:45			
	C2, location of the installation on 16 Aug	17	45	44.50	177	25	21.20			2014/8/16 15:37	2014/9/5 8:20	2014/9/5 8:17
	C3, in the original plan	17	46	45.52	177	21	51.13					
	C3, location verified on 15 Aug	17	46	45.08	177	21	50.50	2.5m	2014/8/15 16:14			
	C3, location of the installation on 17 Aug	17	46	45.10	177	21	50.80			2014/8/17 15:45	2014/9/3 13:37	2014/9/3 13:37
	C4, in the original plan	17	48	10.17	177	21	30.99					
	C4, location verified on 15 Aug	17	48	10.32	177	21	30.20	1.9m	2014/8/15 16:30			
	C4, location of the installation on 17 Aug	17	48	10.70	177	21	31.60			2014/8/17 16:40	2014/9/3 13:07	2014/9/3 13:07
	C5, in the original plan	17	49	04.89	177	21	08.45					
	C5, location verified on 15 Aug	17	49	11.18	177	21	15.47	2.3m	2014/8/15 16:44			
	C5, location of the installation on 18 Aug	17	49	11.60	177	21	14.40			2014/8/18 15:10	2014/9/3 12:42	2014/9/3 12:42
	C6, in the original plan	17	50	26.09	177	20	25.44					
	C6, location verified on 15 Aug	17	50	23.87	177	20	28.08	1.8m	2014/8/15 17:01			
	C6, location of the installation on 18 Aug	17	50	24.90	177	20	28.60			2014/8/18 14:45	2014/9/3 10:54	2014/9/3 10:50

Table 10-9 Installation of Oceanographic Observation Instruments (January 23rd, 2015 – February 27th, 2015)

	Label	Latitude (South)			Longitude (East)			Depth	Time of bathymetry	Date and time of the completion of the installation
		Deg.	Min.	Sec.	Deg.	Min.	Sec.			
DL-3	D1, in the original plan	17	44	36.40	177	24	08.10			
	Verification of the installation location							9.3m	2015/1/24 14:35	
	Location of the installation	17	44	36.70	177	24	08.00			2015/1/24 15:00
	D2, in the original plan	17	45	04.50	177	21	40.70			
	Verification of the installation location							13.6m	2015/1/23 13:05	
	Location of the installation	17	45	04.30	177	21	40.70			2015/1/23 13:30
	D3, in the original plan	17	49	48.70	177	19	41.90			
	Verification of the installation location							10.7m	2015/1/23 11:07	
	Location of the installation	17	49	48.90	177	19	41.90			2015/1/23 11:35
C-EM	C1, in the original plan	17	44	54.80	177	25	39.00			
	Verification of the installation location							2.3m	2015/1/24 15:10	
	Location of the installation	17	44	54.70	177	25	39.20			2015/1/24 15:30
	C2, in the original plan	17	45	44.50	177	25	21.20			
	Verification of the installation location							3.1m	2015/1/24 15:43	
	Location of the installation	17	45	44.60	177	25	21.20			2015/1/24 16:05
	C3, in the original plan	17	46	45.10	177	21	50.80			
	Verification of the installation location							2.9m	2015/1/23 12:30	
	Location of the installation	17	46	45.00	177	21	50.80			2015/1/23 12:45
	C4, in the original plan	17	48	10.70	177	21	31.60			
	Verification of the installation location							2.6m	2015/1/23 12:09	
	Location of the installation	17	48	10.50	177	21	31.60			2015/1/23 12:25
	C5, in the original plan	17	49	11.60	177	21	14.40			
	Verification of the installation location							3.2m	2015/1/23 11:43	
	Location of the installation	17	49	11.40	177	21	14.60			2015/1/23 12:00
	C6, in the original plan	17	50	24.90	177	20	28.60			
	Verification of the installation location							3.2m	2015/1/23 10:27	
	Location of the installation	17	50	24.80	177	20	28.70			2015/1/23 10:55

2) Observation Instruments

a) Wave Meters

The multifunctional oceanographic observation devices (DL-3 of Sonic Corporation) are used for the measurement. The ultrasound and water pressure sensors of the device enable simultaneous measurement of wave height and direction/velocity. The appearance of the device and the way it was installed on the seabed are shown in Figure 10-26 and Figure 10-27, respectively.

The position data of the planned locations of the installation of the observation devices were entered in a handheld GPS receiver in advance and the data entered in the receiver were used to guide the survey vessel to the locations. After arriving at each of the planned installation locations, the location was verified with the GPS observation with another receiver. Then the anchor of the vessel was dropped in the sea to anchor the vessel. After the water depth had been measured with a portable depth sounder (HONOEX PS-7), the device was installed by three divers. One-meter-long single pipes were driven into the seabed with an air lift. A custom-made steel frame was fixed on the pipes. If the installed frame was unsteady, sandbags filled with crushed stones were put on each leg of the frame.

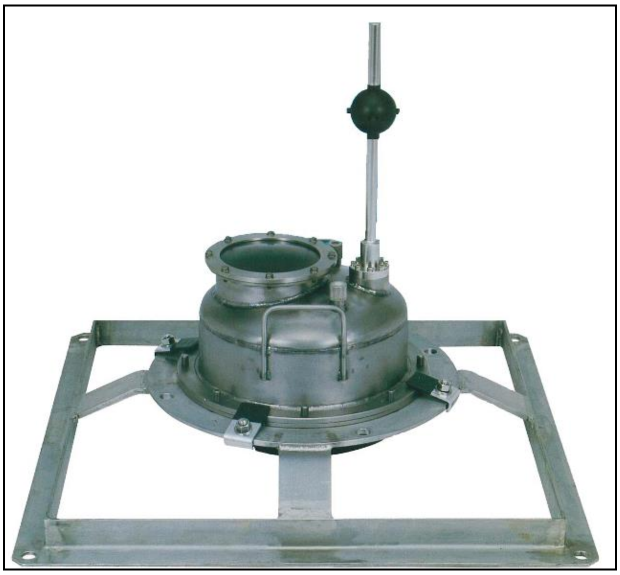


Figure 10-26 Multifunctional Oceanographic Observation Device (DL-3)

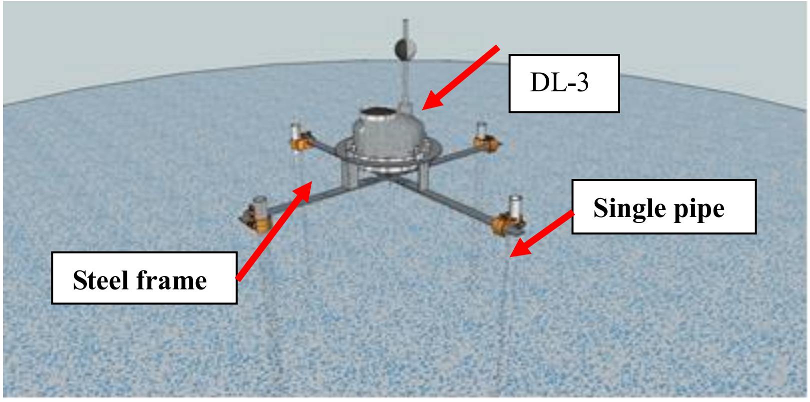


Figure 10-27 Illustration of How DL-3 was Installed

b) Current Meters

Compact electromagnetic current meters (Compact-EM of JFE Advantech) were used in the current survey. Figure 10-28 shows the appearance of the meter. The meter was fixed on the support frame of the wave meter, DL-3.

Figure 10-28 Compact Electromagnetic Current Meter (Compact-EM)

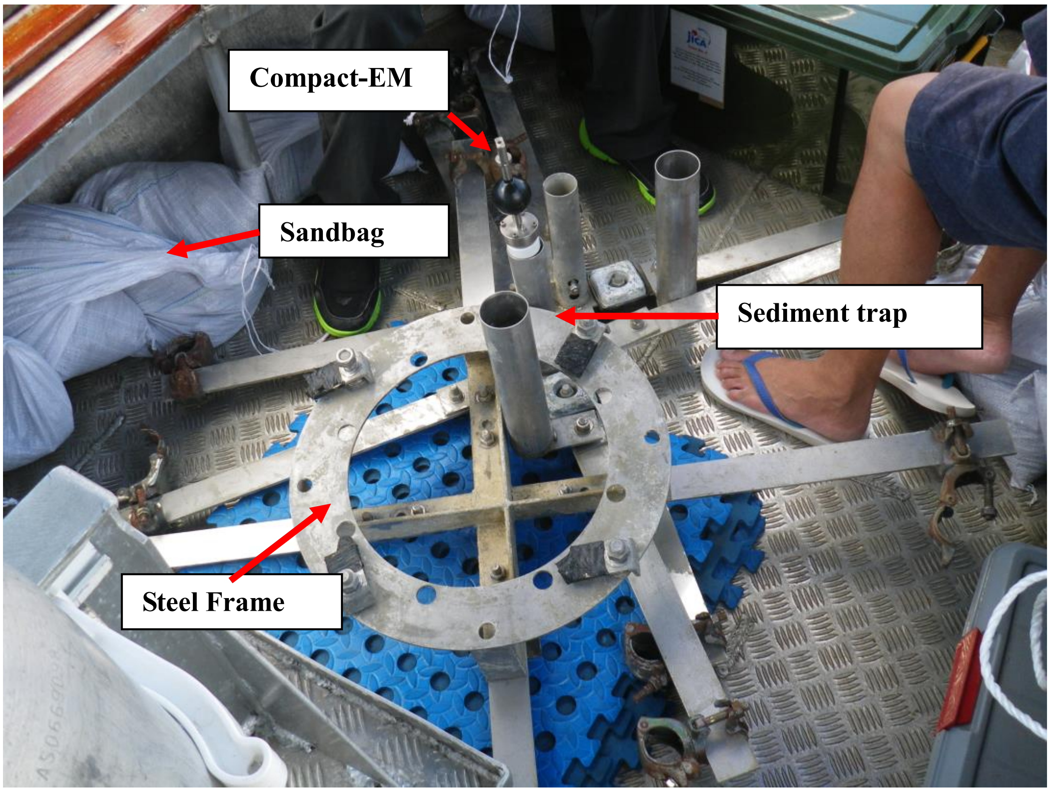


Figure 10-29 Frame, Electromagnetic Current Meter and Sediment Trap

c) Analysis Method of the Results

It is possible to conduct the harmonic analysis of the east-west and north-south velocity components of a measured current separately, separate periodically changing tidal constituents in the current and calculate the amplitude (maximum current velocity) and phase lag of each periodic constituent. The amplitude and phase lag thus obtained are called harmonic constants. Each location has specific harmonic constants, which, it is believed, will not change unless the topography of the location changes significantly. When the current of each tidal constituent at each hour is calculated from the harmonic constants for one period, all the obtained currents are drawn as a vector from the origin on a graph and the end points of the vectors are connected with a line, an ellipse will appear on the graph. If the length of the minor axis of the ellipse is significantly smaller than the major axis, or its flattening is large, the constituent concerned is considered to be predominantly a reciprocating current.

The harmonic analysis also produces a constant tidal constituent which does not change with tidal periodicity. This constant constituent is called a mean current computed over 30 days, also called a permanent or residual current. Harmonic constants of approx. 10 tidal constituents can be obtained from measurement data taken in a 30-day period. Among these constituents, the velocities of K1, O1, M2 and S2 constituents are generally large. Therefore, these four constituents are specifically referred to as four major tidal constituents collectively.

And some of constituent cannot be separated by the harmonic analysis, which are called residual tides.

Table 10-10 Calculated Tidal Constituents and Outline

Code	Name	Period	Coefficient
K1	**Luni-solar diurnal**	**23.93 hrs**	**0.26522**
O1	**Principal lunar diurnal**	**25.82**	**0.18856**
P1	Principal solar diurnal	24.07	0.08775
Q1	Major lunar elliptical diurnal	26.87	0.03651
M2	**Major lunar elliptic semidiurnal**	**12.42**	**0.45426**
S2	**Principal solar semidiurnal**	**12.00**	**0.21137**
N2	Major lunar elliptic semidiurnal	12.66	0.08796
K2	Luni-solar semidiurnal	11.97	0.05752
M4	Principal lunar quarter-diurnal	6.21	—
MS4	Compound (M2 + S2)	6.01	—

The measured current data were processed as shown below.

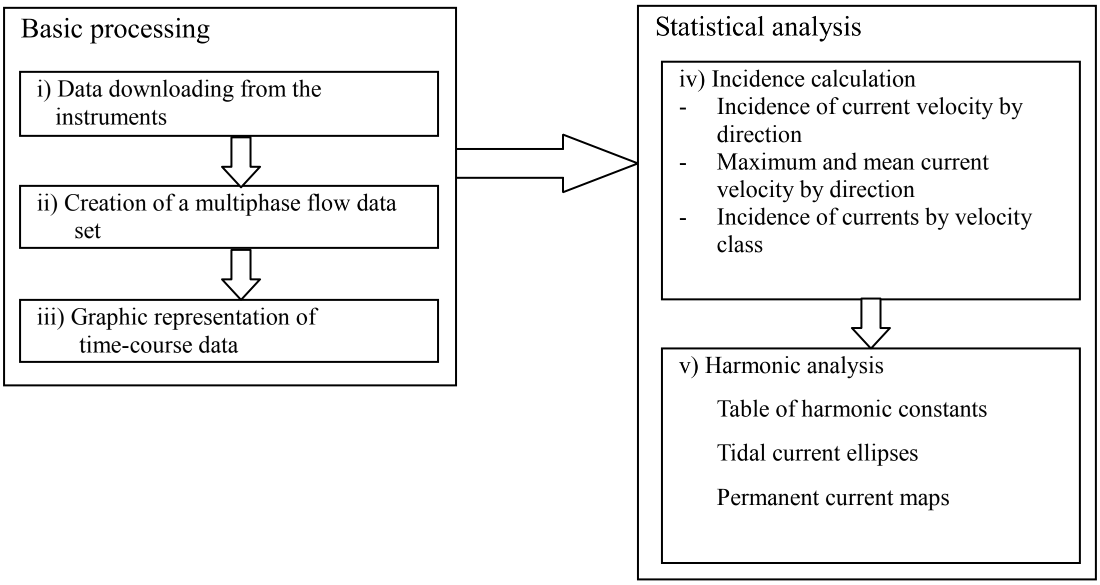


Figure 10-30 Flowchart of Current Data Analysis

The tidal current ellipses of the major four tidal constituents created as outputs of the data analysis have noteworthy characteristics mentioned below.

"The direction of the major axis of ellipse" indicates the axial direction of predominant reciprocating currents. Directions of the major axis may differ between different tidal constituents in some waters. "Amplitude in the direction of the major axis" corresponds to the maximum current velocity of each constituent. "Flattening of ellipse" is the ratio between the major and minor axes of an ellipse. While a flat ellipse indicates predominance of reciprocating currents, an ellipse will be close to a circle in a sea area where current direction rotates. "Phase of current" indicates the time elapsed after the culmination of a hypothetical celestial body around the ellipse. It is the time lag between the culmination and incidence of the maximum current.

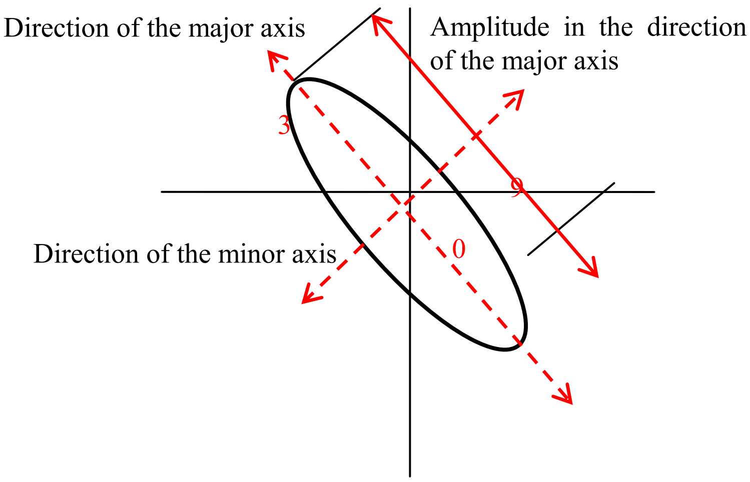


Figure 10-31 Schematic Diagram of Tidal Ellipse

(2) Sediment Survey

1) Geological Environment around Lautoka

The islands of Fiji, which form a vast archipelago, are centered on relatively shallow waters, the Fiji Platform and the Lau Ridge. These islands are located on the fractured Indo-Pacific Plate which has complicated geological features and are near its border with the Pacific Plates. Most of the major islands are composed of basalt and sedimentary rock. Small atolls are composed of limestone. The two largest islands of Fiji, Viti Levu and Vanua Levu, are on the Fiji Platform with many other smaller islands. Strata of the Pliocene, Neogene Period, Cenozoic Era, (approx. 5,000,000 – 2,580,000 years before present) are found in western Lautoka.

Most of the shore of Viti Levu Island is enclosed by reefs. The largest among them is a 100km long reef south of Coral Coast. The northern shore of the island is occupied by very complicated platform reef structures and straits between them. Coral and algae have created reefs at the edge of the platform of shallow water north of the axis of the island arc which crosses Viti Levu Island.

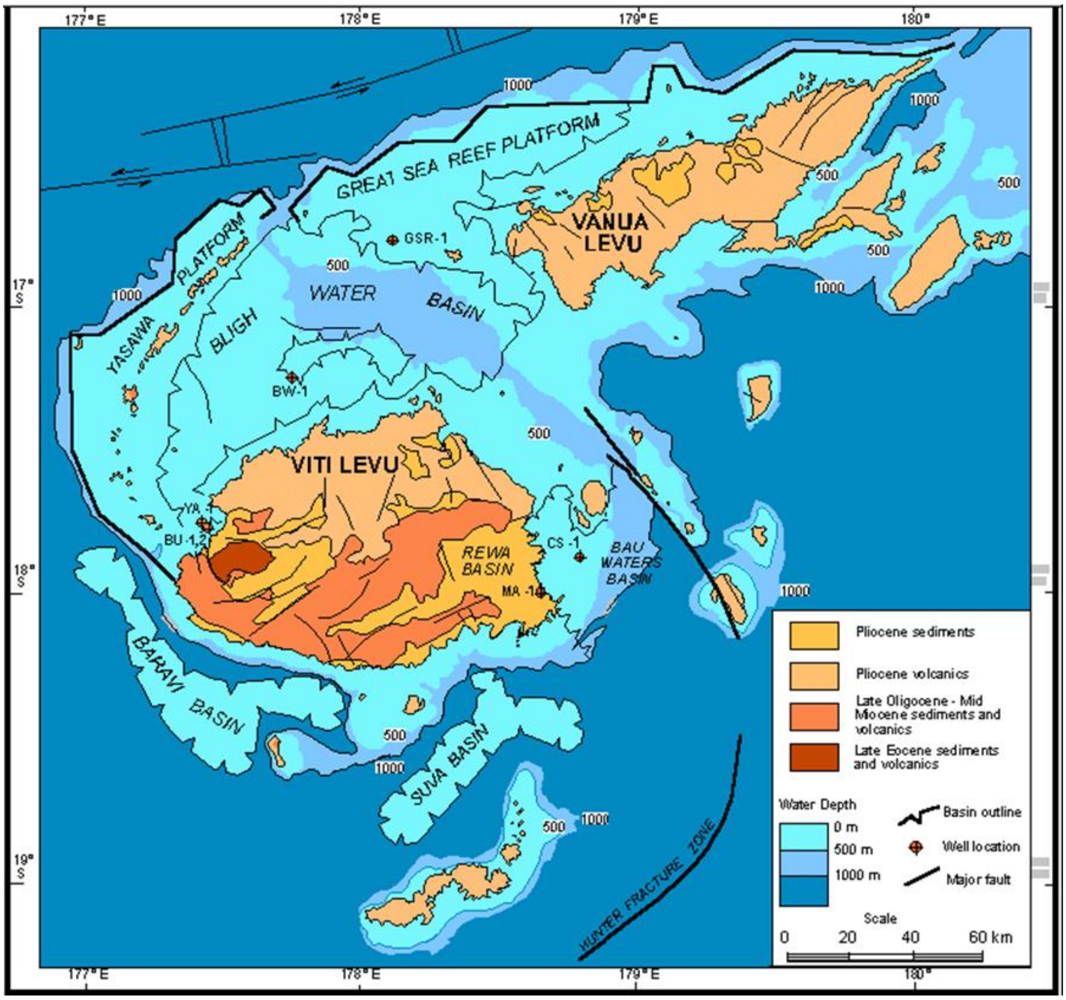


Figure 10-32 Geological Map of Viti Levu Island

Source: Department of Mineral Resources

(http://www.mrd.gov.fj/gfiji/img/maps/geology/Fijigeo.gif Adapted From Rodd (1993))

2) Sumpling Method

The use of the bed load samplers (e.g. Macintosh type) in the sediment survey was initially planned. However, the method of sampling by divers was adopted because of the lack of knowledge of the characteristics of the sea bed sediment in the Republic of Fiji, the need to reduce the weight of instruments to be transported by air, the reliability in sampling and the advantage that conditions of the seabed and sediments of areas other than the sampling points can be visually observed by the divers. Samples were collected at 52 locations in the sampling period between August 30th, 2014 and September 4th, 2014. It was not possible to collect samples at the planned sampling points in a private lot and a mangrove forest because of inaccessibility.

Sediment Tests

The analysis of the collected sediment samples was commissioned from two laboratories in the Republic of Fiji, Entec, Ltd. and Koronivia Research (MOA). Table 10-12 shows the types of analysis conducted. Sieve analysis was implemented as the primary analysis. In addition, other types of analysis including density analysis were conducted in order to characterize the collected samples. See the references attached hereto for the details of the analysis results.

Figure 10-33 Collected Sediment Sample

Table 10-11 Sediment Sampling Locations and Dates

No.	SampleName	UTM Y (North)	UTM X (East)	Lat ddmmss.ss	Lon ddmmss.ss	Date
1	SP1	8032132.391	538486.646	-17° 46' 30.18"	177° 21' 54.16"	2014/8/30
2	SP2	8032303.385	537993.095	-17° 46' 28.76"	177° 21' 20.89"	2014/8/30
3	SP3	8032460.675	537531.924	-17° 47' 19.78"	177° 21' 55.63"	2014/8/30
4	SP4	8032612.674	537055.549	-17° 47' 18.09"	177° 21' 12.59"	2014/8/30
5	SP5	8031669.597	538330.533	-17° 49' 30.55"	177° 21' 22.85"	2014/8/30
6	SP6	8031750.118	538081.772	-17° 49' 19.45"	177° 20' 45.07"	2014/8/30
7	SP7	8031834.651	537849.880	-17° 50' 04.04"	177° 20' 35.17"	2014/8/30
8	SP8	8031203.324	538163.100	-17° 49' 47.65"	177° 20' 20.62"	2014/8/30
9	SP9	8031270.961	537931.946	-17° 50' 36.43"	177° 19' 57.01"	2014/8/30
10	SP10	8031342.892	537687.504	-17° 50' 23.01"	177° 19' 46.35"	2014/8/30
11	SP11	8031500.237	537221.215	-17° 47' 52.57"	177° 21' 47.30"	2014/8/30
12	SP12	8031655.488	536745.109	-17° 47' 47.04"	177° 21' 30.53"	2014/8/30
13	SP13	8030715.261	538011.217	-17° 47' 41.95"	177° 21' 14.85"	2014/8/30
14	SP14	8030796.572	537786.927	-17° 47' 37.03"	177° 20' 58.66"	2014/8/30
15	SP15	8030858.647	537529.048	-17° 48' 07.64"	177° 21' 42.03"	2014/8/30
16	SP16	8031033.151	537062.776	-17° 48' 05.04"	177° 21' 33.57"	2014/8/30
17	SP17	8031180.856	536585.369	-17° 48' 02.30"	177° 21' 25.69"	2014/8/30
18	SP18	8030251.935	537862.363	-17° 48' 22.83"	177° 21' 36.37"	2014/8/30
19	SP19	8030309.035	537626.845	-17° 48' 20.64"	177° 21' 28.52"	2014/8/30
20	SP20	8030398.871	537388.465	-17° 48' 18.31"	177° 21' 20.21"	2014/8/30
21	SP21	8029759.438	537714.063	-17° 48' 13.22"	177° 21' 04.36"	2014/8/30
22	SP22	8029917.624	537239.108	-17° 48' 08.20"	177° 20' 48.18"	2014/8/30
23	SP23	8030075.720	536761.279	-17° 48' 38.72"	177° 21' 31.25"	2014/8/30
24	SP24	8030233.475	536282.789	-17° 48' 36.08"	177° 21' 23.62"	2014/8/30
25	SL2-0m	8034659.595	538748.962	-17° 46' 30.32"	177° 21' 56.04"	2014/9/1
26	SL2-2m	8034664.043	538693.585	-17° 48' 34.08"	177° 21' 14.86"	2014/8/30
27	SL2-7m	8034709.555	537714.006	-17° 48' 28.43"	177° 20' 59.01"	2014/8/30
28	SL5-0m	8033155.790	538806.921	-17° 47' 19.25"	177° 21' 58.11"	2014/9/1
29	SL5-2m	8033139.856	538733.817	-17° 48' 23.65"	177° 20' 42.78"	2014/8/30
30	SL5-7m	8033193.995	537466.619	-17° 48' 53.80"	177° 21' 26.22"	2014/8/30
31	SL18-0m	8029056.583	537984.431	-17° 49' 32.69"	177° 21' 30.44"	2014/9/2
32	SL18-2m	8029122.891	537760.977	-17° 48' 51.96"	177° 21' 18.21"	2014/8/30
33	SL18-7m	8029465.889	536649.689	-17° 48' 49.05"	177° 21' 10.11"	2014/8/30
34	SL22-0m	8027153.665	537096.103	-17° 50' 34.66"	177° 21' 00.39"	2014/9/2
35	SL22-2m	8028096.156	536355.729	-17° 49' 09.84"	177° 21' 21.21"	2014/8/30
36	SL22-7m	8028600.762	535928.437	-17° 49' 04.72"	177° 21' 05.07"	2014/8/30
37	SL25-0m	8026666.406	535570.049	-17° 50' 50.61"	177° 20' 08.57"	2014/9/2
38	SL25-2m	8027102.857	535230.818	-17° 48' 59.60"	177° 20' 48.83"	2014/8/30
39	SL25-7m	8027515.740	534917.544	-17° 48' 54.50"	177° 20' 32.56"	2014/8/30
-	NL3-0m	-	-	-	-	Inaccessible
40	NL3-2m	8038484.016	544768.224	-17° 44' 25.47"	177° 25' 20.18"	2014/9/1
41	NL3-7m	8038111.905	544185.853	-17° 44' 37.62"	177° 25' 00.44"	2014/9/1
42	NL7-0m	8037008.401	546057.870	-17° 45' 13.39"	177° 26' 04.09"	2014/9/4
43	NL7-2m	8037019.674	545654.429	-17° 45' 13.05"	177° 25' 50.39"	2014/9/1
44	NL7-5m	8037004.849	544917.903	-17° 45' 13.59"	177° 25' 25.38"	2014/9/1
45	NL10-0m	8035718.324	545165.469	-17° 45' 55.43"	177° 25' 33.89"	2014/9/4
46	NL10-2m	8035774.801	545112.734	-17° 45' 53.60"	177° 25' 32.09"	2014/9/1
47	NL10-5m	8036446.500	544583.465	-17° 45' 31.78"	177° 25' 14.06"	2014/9/1
48	NL13-0m	8034988.560	543763.335	-17° 46' 19.28"	177° 24' 46.32"	2014/9/4
49	NL13-2m	8035319.797	543768.902	-17° 46' 08.50"	177° 24' 46.49"	2014/9/1
50	NL13-5m	8035925.398	543755.213	-17° 45' 48.80"	177° 24' 45.98"	2014/9/1
-	NL17-0m	-	-	-	-	Inaccessible
51	NL17-2m	8035963.013	541770.257	-17° 45' 47.71"	177° 23' 38.56"	2014/9/1
52	NL17-7m	8036870.609	541755.707	-17° 45' 18.18"	177° 23' 38.00"	2014/9/1

Table 10-12 Conducted Sediment Tests

Laboratory	Surveying line no.	Sieve analysis			Sedimentation analysis	Density analysis	Water content	Loss on ignition	LL/PL	Remarks
		±0.0m	-2.0m	-5.0m(-7.0m)						
Koronivia	NL3	×	○1	○1						Private lot
Koronivia	NL 7	○1	○1	○1						
Koronivia	NL10	○1	○1	○1						
ENTEC	NL13	◎1	◎1	◎1	◎3	◎3	◎3	◎3	◎3	
Koronivia	NL17	×	○1	○1						Mangrove forest
Koronivia	SL2	○1	○1	○1						
Koronivia	SL5	○1	○1	○1						
Koronivia	SL18	○1	○1	○1						
Koronivia	SL22	○1	○1	○1						
Koronivia	SL25	○1	○1	○1						
Koronivia	SP1	○1								
Koronivia	SP2	○1								
Koronivia	SP3	○1								
Koronivia	SP4	○1								
Koronivia	SP5	○1								
Koronivia	SP6	○1								
Koronivia	SP7	○1								
Koronivia	SP8	○1								
Koronivia	SP9	○1								
Koronivia	SP10	○1								
Koronivia	SP11	○1								
Koronivia	SP12	○1								
ENTEC	SP13	◎1			◎1	◎1	◎1	◎1	×	Sample unusable for the analysis
ENTEC	SP14	◎1			◎1	◎1	◎1	◎1	◎1	
ENTEC	SP15	◎1			◎1	◎1	◎1	◎1	×	Sample unusable for the analysis
ENTEC	SP16	◎1			◎1	◎1	◎1	◎1	◎1	
ENTEC	SP17	◎1			◎1	◎1	◎1	◎1	◎1	
Koronivia	SP18	○1								
Koronivia	SP19	○1								
Koronivia	SP20	○1								
Koronivia	SP21	○1								
Koronivia	SP22	○1								
Koronivia	SP23	○1								
Koronivia	SP24	○1								
Koronivia	C1 (Dry season)	○1			○1					
Koronivia	C2 (Dry season)	×			×					Sample unusable for the analysis
Koronivia	C3 (Dry season)	○1			○1					
Koronivia	C4 (Dry season)	○1			○1					
Koronivia	C5 (Dry season)	○1			○1					
Koronivia	C6 (Dry season)	○1			○1					
Koronivia	C1 (Rainy season)	○1			○1					
Koronivia	C2 (Rainy season)	○1			○1					
Koronivia	C3 (Rainy season)	○1			○1					
Koronivia	C4 (Rainy season)	○1			○1					
Koronivia	C5 (Rainy season)	○1			○1					
Koronivia	C6 (Rainy season)	○1			○1					
Number of the analyzed samples		43	10	10	19	8	8	8	6	
Number of samples not analyzed		0	0	0	0	0	0	0	△2	
Number of the analysis conducted		43	10	10	19	8	8	8	6	

(3) Suspended solids

1) Method

The suspended solids were measured weights of all sediment trapped in the trap-tubes (cylindrical containers, φ6.05 cm × L 26 cm) attached to the current meters in a period of 15 days and nights or 30 days and nights were characterized in the observation. The days on which the traps were installed and retrieved were not included in the sampling period.

2) Results

The weights of the trapped sediment in the observation terms are described in the following.

Table 10-13 Results of Suspended Sediment Trap (dry season)

Sampling locations (dry season)	Date of installation Date of retrieval	Sampling depth (m)	Sample weight (g)	Sampling period (hours)	Equivalent diameter (μ) Sedimentation weight (g)	Sedimentation ratio (%)
C1	Aug. 16th, 2014 Sep. 5th, 2014	2.0	1.57	19 days (456 hrs)	φ0.0045 1.32	84.12
C2	Aug. 16th, 2014 Sep. 5th, 2014	2.6	Unusable for the analysis	19 days (456 hrs)	Unusable for the analysis	Unusable for the analysis
C3	Aug. 17th, 2014 Sep. 3rd, 2014	2.5	5.67	16 days (384 hrs)	φ0.0028 1.30	23.00
C4	Aug. 17th, 2014 Sep. 3rd, 2014	1.9	4.17	16 days (384 hrs)	φ0.0037 1.75	41.89
C5	Aug. 18th, 2014 Sep. 3rd, 2014	2.3	9.12	15 days (360 hrs)	φ0.0028 1.67	18.28
C6	Aug. 18th, 2014 Sep. 3rd, 2014	1.8	8.26	15 days (360 hrs)	φ0.0028 1.31	15.80
Total			28.79	100 days		
Mean			0.012g/h	(2400 hrs)		

The suspended sediment (SS) analysis was conducted with the samples taken in January and February 2015. In the SS analysis, sample solution sieved through a 2mm mesh sieve is filtered with glass-fiber filter paper with the pore diameter of 1μm and the materials remaining in the filter paper are washed, dried and weighed. SS thus obtained is presented with the unit of mg/L. The substance remaining after sample solution is evaporated to dryness and dried at 105 – 110ºC is called total evaporation residue.

Table 10-14 Results of Suspended Sediment Trap (rainy season)

Sampling locations (rainy season)	Date of installation Date of retrieval	Sampling depth (m)	Sample weight (g)	Sapling period (hours)	Suspended sediment concentration (mg/L) Sediment weight (g)	Sedimentation ratio (%)
C1	Jan. 24th, 2015 Feb. 25th, 2015	2.3	8.78	31 days (744 hrs)	20,332 2.06	23.46
C2	Jan. 24th, 2015 Feb. 25th, 2015	3.1	10.79	31 days (744 hrs)	16,306 0.13	1.20
C3	Jan. 23rd, 2015 Feb. 25th, 2015	2.9	67.43	32 days (768 hrs)	29,868 5.67	8.41
C4	Jan. 23rd, 2015 Feb. 25th, 2015	2.6	102.32	32 days (768 hrs)	68,704 4.11	4.02
C5	Jan. 23rd, 2015 Feb. 24th, 2015	3.2	92.13	31 days (744 hrs)	49,687 9.08	9.86
C6	Jan. 23rd, 2015 Feb. 24th, 2015	3.2	75.32	31 days (744 hrs)	73,230 8.31	11.03
Total			356.77	188 days		
Mean			0.079g/h	(4512 hrs)		

10.3 Conditions of Marine Phenomena

10.3.1 High Tides

(1) Tidal Levels

The astronomical tidal levels at Lautoka (as presented in elevation) are as follows:

Mean High Water Springs (MHWS) E.L. +0.85m
Mean High Water Neaps (MHWN) E.L. +0.55m
Mean Sea Water Level (MSL) E.L. +0.00m
Mean Low Water Neaps (MHWN) E.L. -0.45m
Mean Low Water Springs (MHWS) E.L. -0.75m
Lowest Astronomical Tide (LAT) E.L. -1.05m

The instruments were installed at the locations provided in Table 10-15.

Table 10-15 Locations of Observation

Station name	Lautoka	Latitude	Longitude	Enclosure Elevation
Tide gauge	Lautoka Wharf	17° 36' 19" S	177° 26' 17" E	+0.00m

(2) High Tides

The tide level has been measured at Lautoka every hour since October 24th, 1992. The table below shows the highest, lowest and mean tide levels of each year since then.

Table 10-16 Highest, Lowest and Mean Sea Levels (Lautoka: 1992 – 2010)

Year	Highest sea level			Lowest sea level			Year	MSL
	Month	Day	Sea surface height (m)	Month	Day	Sea surface height (m)		Sea surface height (m)
1992	12	10	+1.42	10	25	-0.97	1992	+0.10
1993	11	13	+1.20	1	10	-1.10	1993	+0.05
1994	12	3	+1.18	5	26	-1.12	1994	+0.06
1995	12	23	+1.24	6	15	-1.18	1995	+0.06
1996	1	20	+1.24	7	31	-1.04	1996	+0.11
1997	3	8	+1.59	8	19	-1.05	1997	+0.12
1998	1	29	+1.16	12	31	-1.11	1998	+0.02
1999	11	24	+1.18	1	2	-1.19	1999	+0.06
2000	1	21	+1.31	12	13	-1.00	2000	+0.14
2001	2	9	+1.29	8	20	-1.07	2001	+0.12
2002	11	5	+1.25	5	26	-0.98	2002	+0.12
2003	11	24	+1.15	6	15	-1.07	2003	+0.06
2004	7	31	+1.14	7	2	-1.03	2004	+0.09
2005	2	9	+1.19	8	21	-1.09	2005	+0.07
2006	1	31	+1.18	2	28	-1.05	2006	+0.11
2007	9	28	+1.24	5	18	-1.00	2007	+0.14
2008	12	13	+1.24	6	5	-0.98	2008	+0.17
2009	2	9	+1.31	1	11	-0.90	2009	+0.24
2010	1	31	+1.28	8	11	-1.08	2010	+0.10
	Highest		+1.59	Lowest		-1.19	Mean	+0.10

(Note) As the sea levels were measured from DL, 1.150m was subtracted from all the sea level measurements to make them presented in elevation.

Table 10-17 shows the five highest sea levels observed. All these high sea levels were observed in the period between January and March in the rainy season and when the barometric pressure was low because of the passing cyclones. The two highest ones observed in March 1997 and December 1992 caused severe flood damage.

Table 10-17 Sea Levels at Time of Flood Tides and Days of Occurrence

Rank	Year	Day of occurrence	Time of measurement	Highest sea level (m)	Barometric pressure at the time of measurement (hP)	Remarks (cyclone name)
1	1997	Mar. 8th	6:00	1.593 (2.743)	986.8	Cyclone Gavin, Mar. 3rd – 12th
2	1992	Dec. 10th	7:00	1.422 (2.572)	996.3	Cyclone Joni, Dec. 6th – 13th
3	2009	Feb. 9th	6:00	1.314 (2.464)	1009.0	Cyclone Vincent, Feb. 5th – 15th
4	2000	Jan. 21st	6:00	1.306 (2.456)	1001.1	Cyclone #200006, Jan. 18th – 23rd
5	2001	Feb. 9th	7:00	1.293 (2.443)	1004.6	Cyclone Freddy, Feb. 3rd – 15th

(Note) The highest sea levels are presented in elevation. The values in the parentheses are those presented relative to DL.

10.3.2 Waves

(1) Ocean Waves (Deep-water Waves)

As there are no directly observed data of ocean waves around the Fiji Islands, the Global Wave Prediction Database (Japan Weather Association) are choice for this study. This database consists of data on significant waves which are predicted from the wind velocity of ocean surface provided by the National Centers for Environmental Prediction (NCEP) using a wave prediction model WAM. The database contains predicted hourly data of the significant wave height, period and direction of waves at each grid point on the 0.5º grid of the entire Pacific Ocean since 1951.

The grid point at 176.5°E/17.0°S (water depth=-2209m) was selected as the location of the ocean wave predicting point because the waves at this location were expected to have significant influence to Nadi Bay and the estuary of the Nadi River. (See Figure 10-34) The wave prediction was conducted for a five-year period, the four-year period until March 2012 for which the meteorological observation data at Lautoka on the island concerned were available and the one-year period from April 2014 in which the field measurement of waves was taken in this project. These ocean waves are predicted with no concerned about the topography of the islands of Fiji as deep-water waves. And the wave shoring deformation should be calculated using the topographic data of the Islands to convert them into the wave height at the project sites.

Figure 10-35 to Figure 10-37 show the frequency distributions of wave direction, significant wave height and wave period at the ocean wave predicting point.

The data in these figures show that the significant wave heights of the ocean waves were at least 1.0m and their periods were at least 6 seconds. The largest proportions of the waves were in the ranges of significant wave height between 1.5m and 2.5m and period between 7.0 seconds and 10.0 seconds. In fact, 80% and 86% of the ocean waves were within these ranges of significant wave height and period, respectively. The many of the wave directions was between south and east. In fact, the waves in this direction range accounted for 73% of all the waves. As the main islands of Fiji are in this direction, a large proportion of offshore waves are influenced by the shielding effect of the islands.

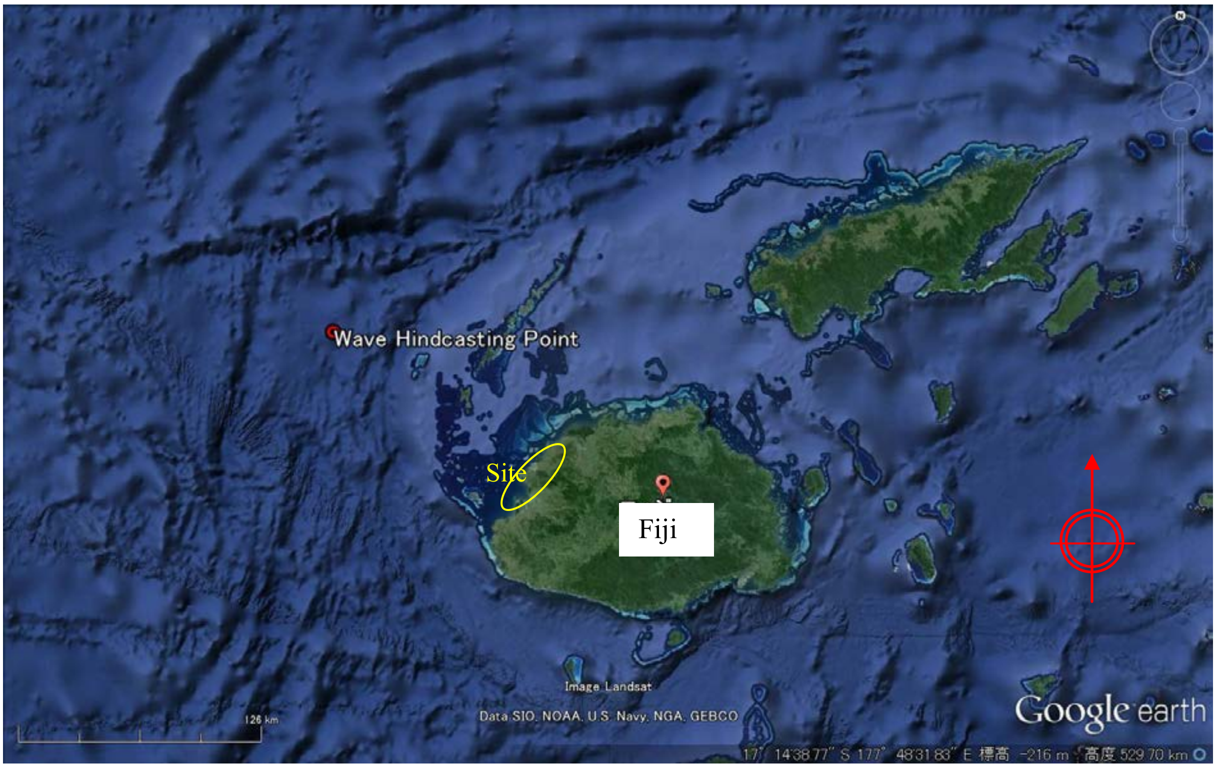


Figure 10-34 Location of Ocean Wave Predicting Point

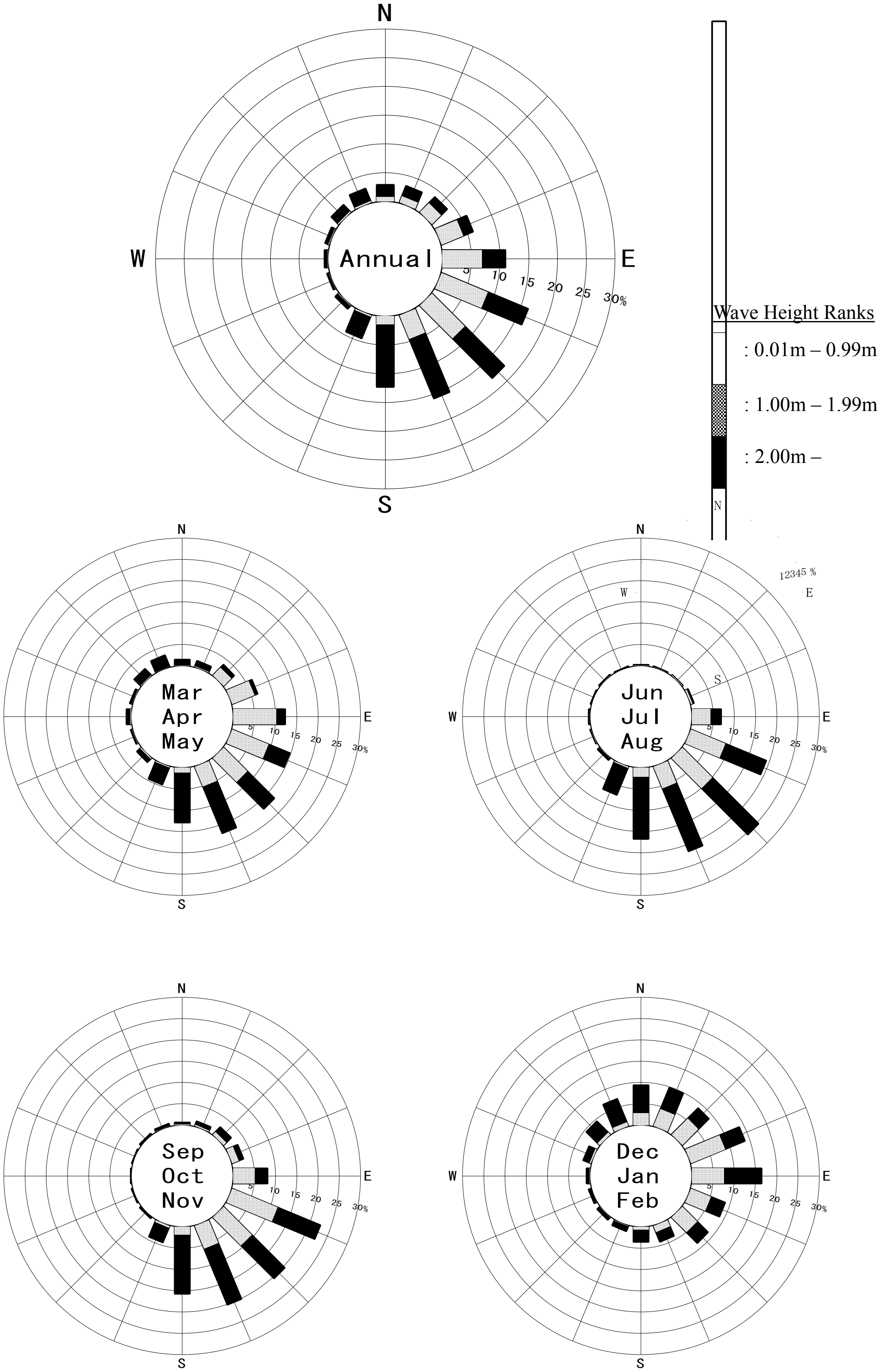


Figure 10-35 Frequency Distribution of the Ocean Wave Direction

(Between April 2009 and March 2013 and between April 2014 and March 2015)

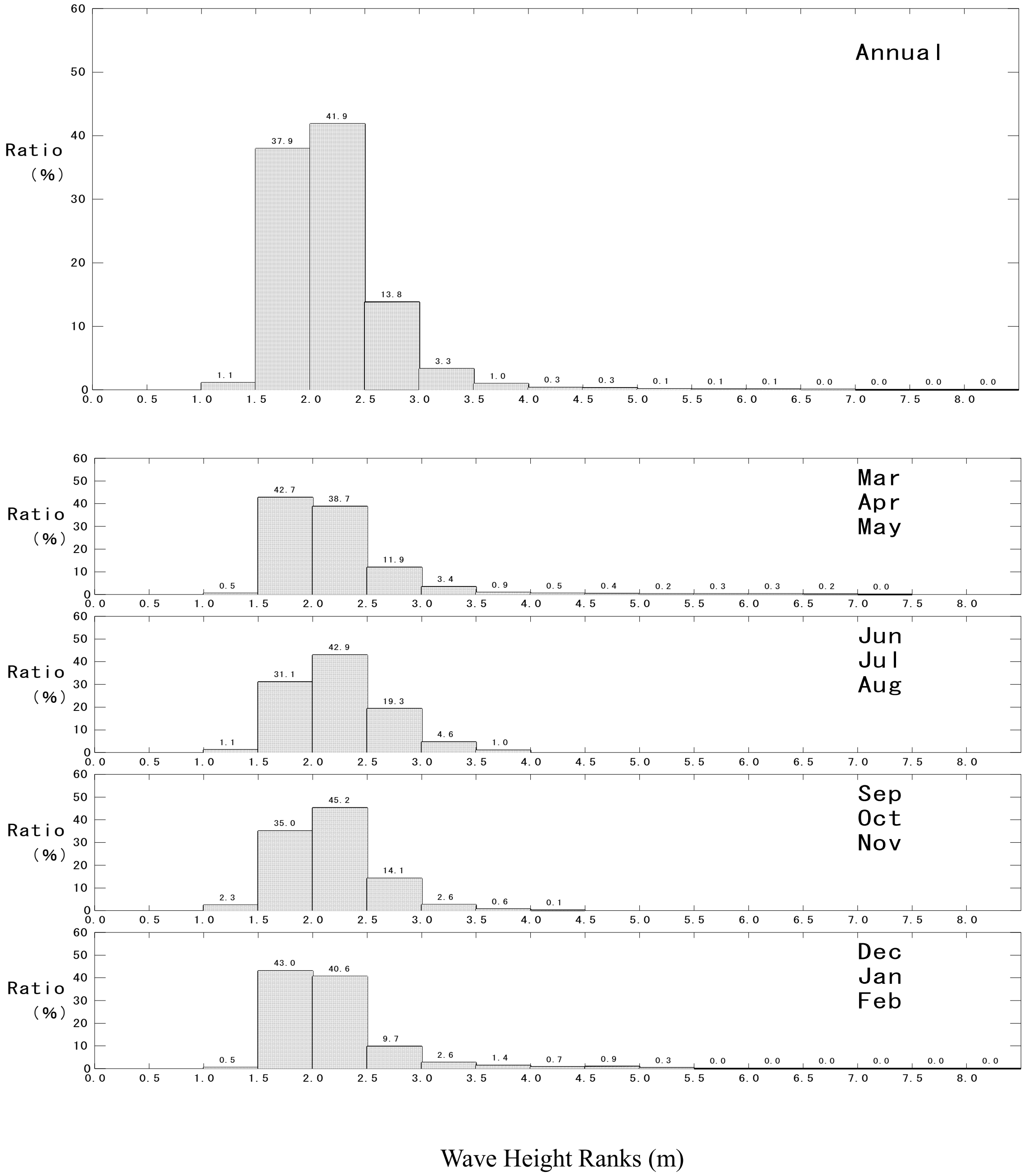


Figure 10-36 Frequency Distribution of the Ocean Significant Wave Heights

(Between April 2009 and March 2013 and between April 2014 and March 2015)

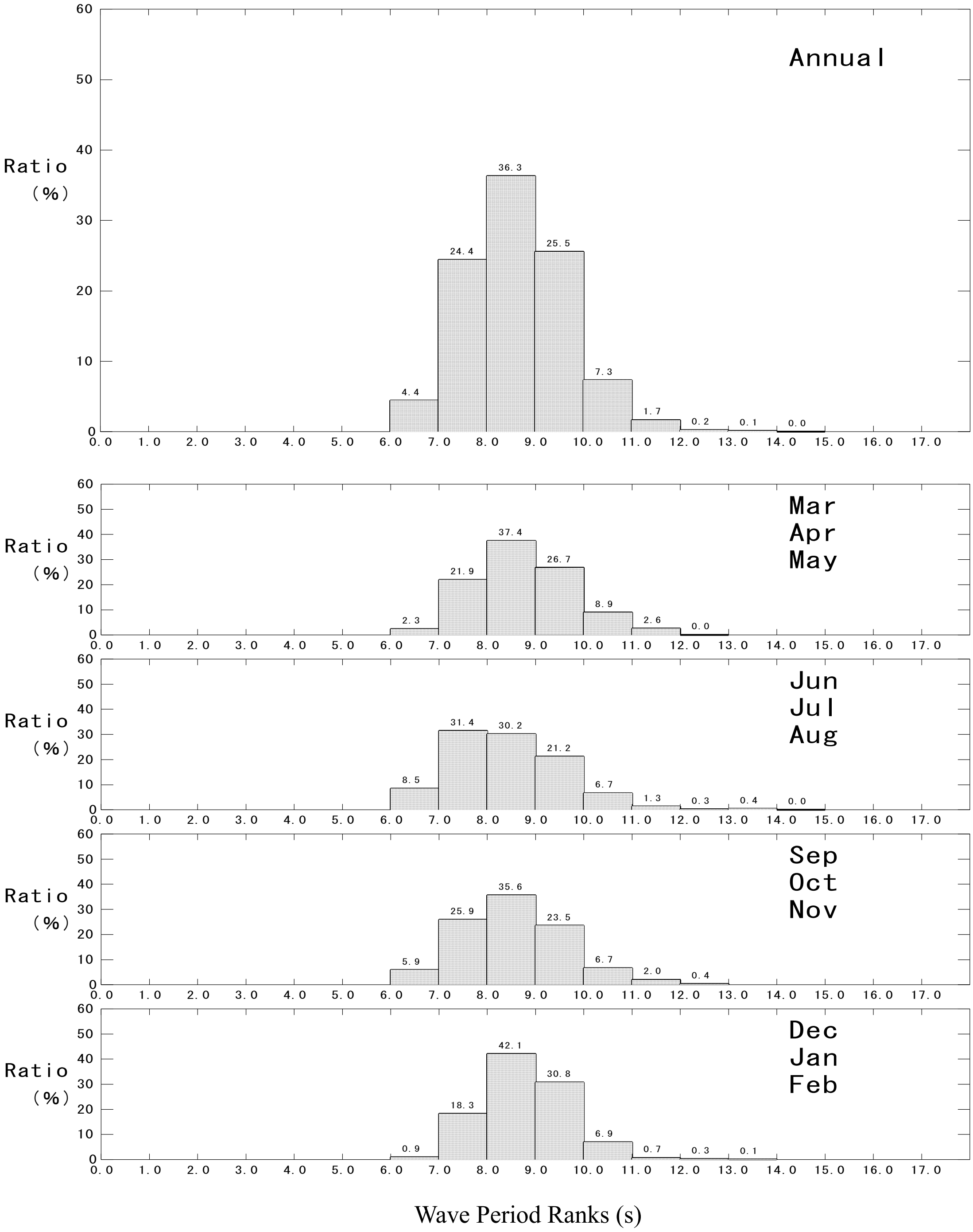


Figure 10-37 Frequency Distribution of the Ocean Wave Periods

(Between April 2009 and March 2013 and between April 2014 and March 2015)

Table 10-18 below shows the five records with the largest significant wave height in each year.

The wave with the largest wave height, Hs = 8.44m, T = 9.7s and the direction = SSE, is predicted to have occurred at 01:00, December 17th, 2012.

Table 10-18 The Largest Significant Wave Heights of each year

(Between April 2009 and March 2013 and between April 2014 and March 2015)

Year	No	month	day	time	Height(m)	Period(s)	Angle(N° E)	Direction
2009.4 ～ 2010.3	1	3	15	11	5.84	10.5	119	ESE
	2	12	13	8	4.89	8.4	75	ENE
	3	12	10	21	4.17	8.0	108	ESE
	4	6	19	18	3.52	7.1	97	E
	5	3	18	0	3.37	11.0	219	SW
2010.4 ～ 2011.3	1	2	21	20	5.29	9.3	329	NNW
	2	9	20	4	4.20	10.3	169	S
	3	1	8	19	3.64	7.3	360	N
	4	6	15	19	3.48	7.5	128	SE
	5	9	24	2	3.26	10.6	184	S
2011.4 ～ 2012.3	1	3	31	13	6.53	9.3	315	NW
	2	2	1	12	5.41	9.0	329	NNW
	3	2	4	20	4.91	8.2	312	NW
	4	1	31	7	4.51	8.0	326	NW
	5	7	13	13	3.98	11.2	195	SSW
2012.4 ～ 2013.3	1	12	17	1	8.44	9.7	163	SSE
	2	4	2	9	5.17	8.7	322	NW
	3	1	29	19	3.98	8.0	266	W
	4	3	12	17	3.44	8.7	28	NNE
	5	3	7	1	3.41	7.8	279	W
2014.4 ～ 2015.3	1	3	12	13	7.02	11.9	343	NNW
	2	3	15	0	4.13	8.4	319	NW
	3	10	6	0	4.04	11.2	186	S
	4	5	17	15	3.81	7.9	166	SSE
	5	7	5	11	3.66	11.5	195	SSW
Average					4.56	9.2	221	NW
Average of Maximum in Each Year					6.62	10.14	−	−
Maximum					8.44	11.9	−	−

(2) Waves inside Reef

Coral reefs have developed around the project site to enclose a large area of project site. Therefore, it is considered that transmitted waves, waves reaching the project site from the open sea through low points on the reefs and gaps between them, and wind waves generated inside the reefs coexist in the sea inside the reefs.

Figure 10-39 and Figure 10-40 show the significant wave heights and periods of the waves inside reef observed at the observation points, D1, D2 and D3 (Figure 10-38. The significant wave heights of most of the observed waves were 0.5m or less and nearly 90% of them had periods between 2.0 seconds and 5.0 seconds. The observed direction of the waves at the observation points D1 and D3, where incidence waves to Nadi Bay and the estuary of the Nadi River were observed, was predominantly between NW and WNW.

Waves with a period longer than 6 seconds were observed inside the reefs. Since waves with such a long period cannot be generated within the reefs because of the limited fetch, these waves of a long period are considered as a result of the invasion of offshore waves.

Table 10-19 shows the estimated appearance ratio of the maximum and significant waves observed at each hour having a period of 6 seconds or longer as ocean waves. The appearance ratio of the waves with a period of 6 seconds or longer, which was considered as invaded ocean waves, was large in the rainy season when many cyclones hit Fiji. In fact, 41% of the maximum waves in the rainy season had such a period. Even in the dry season, nearly 20% of the maximum waves had a period of 6 seconds or longer.

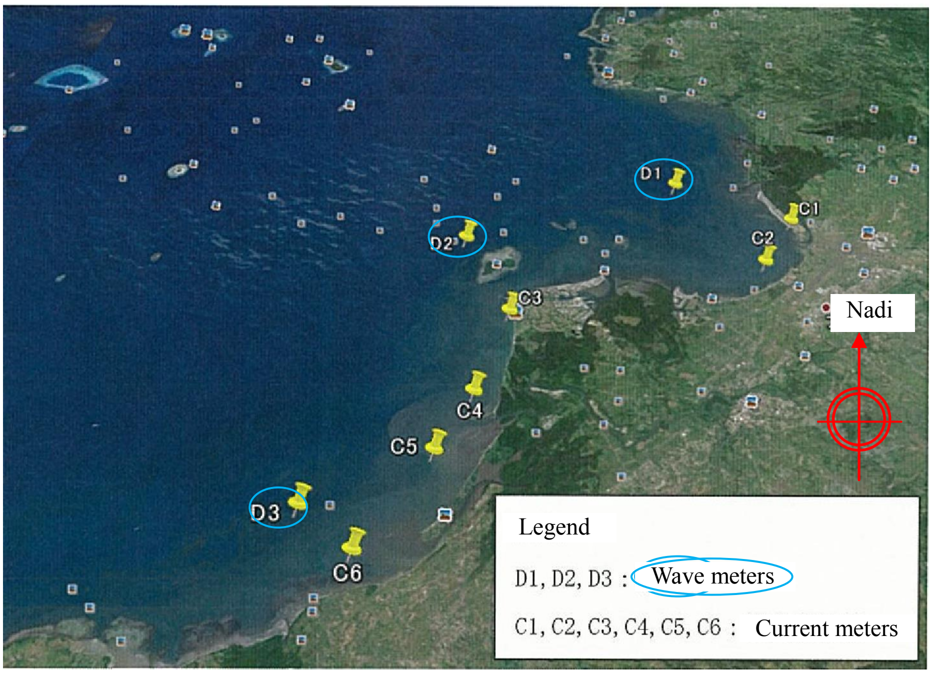


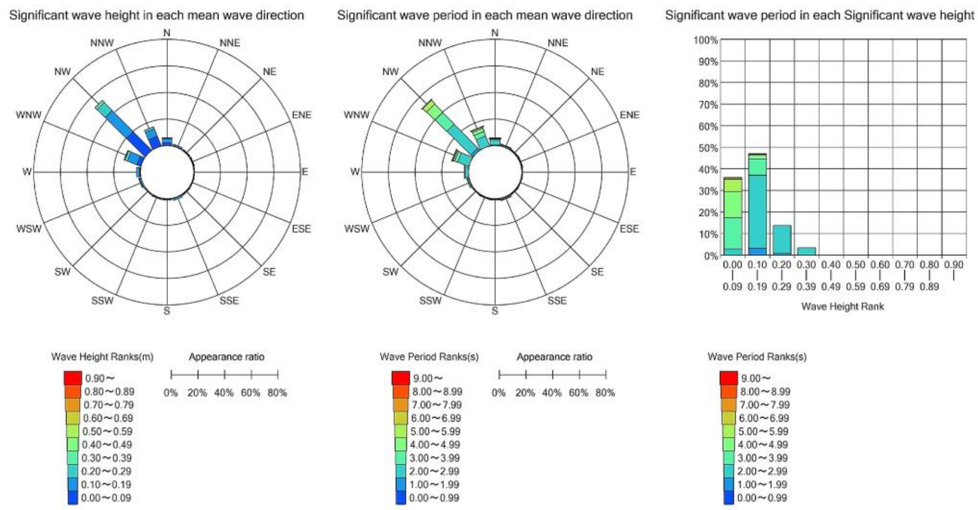
Figure 10-38 Locations of Observation Points

Table 10-19 Appearance Ratio of Waves Inside Reef with Period of 6 Second or Longer

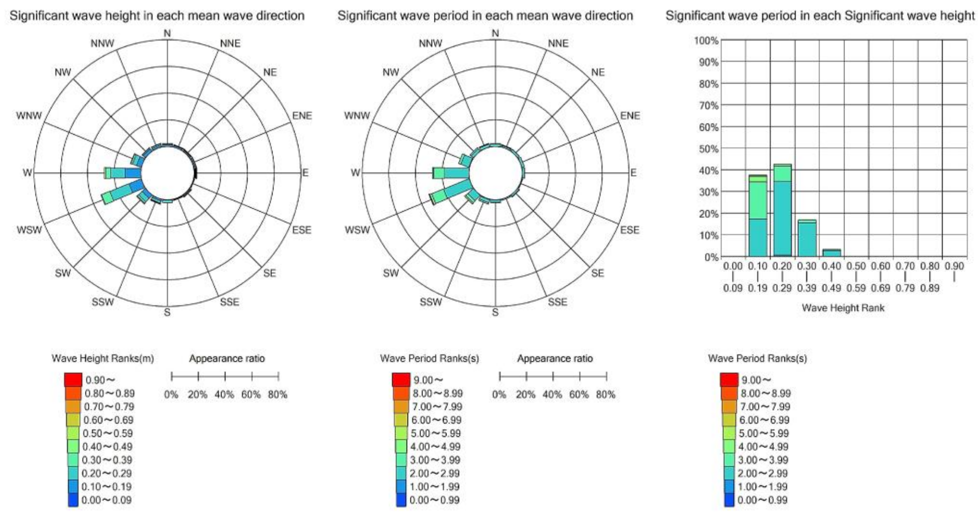
	D1	D2	D3	Total
Dry season	16.2 (1.28) %	12.04 (0.00) %	31.23 (7.61) %	19.82 (2.96) %
Rainy season	43.65 (8.88) %	34.52 (3.43) %	43.58 (15.69) %	41.25 (9.33) %

Note) The values outside and in the parentheses appearance ratio of the maximum wave having a period of 6 seconds or longer and the significant wave having a period of 6 seconds or longer, respectively.

Observation point D1



Observation point D2



Observation point D3

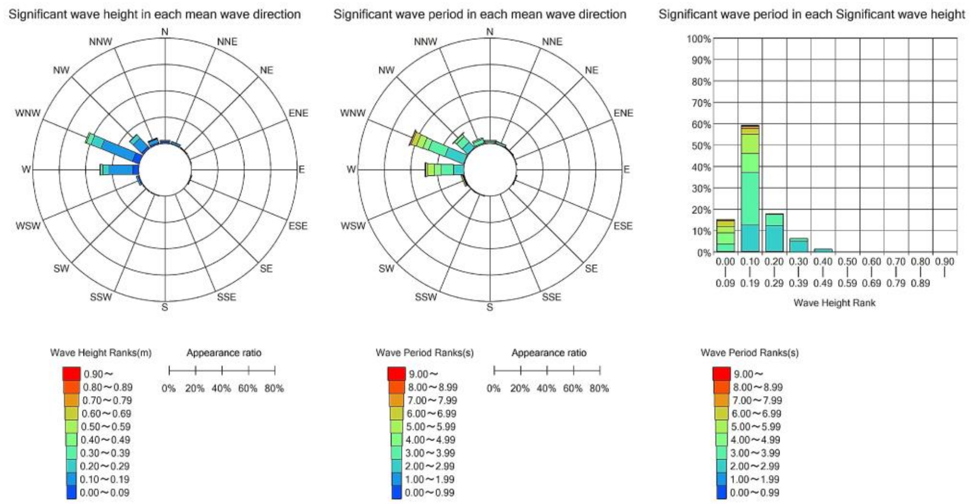
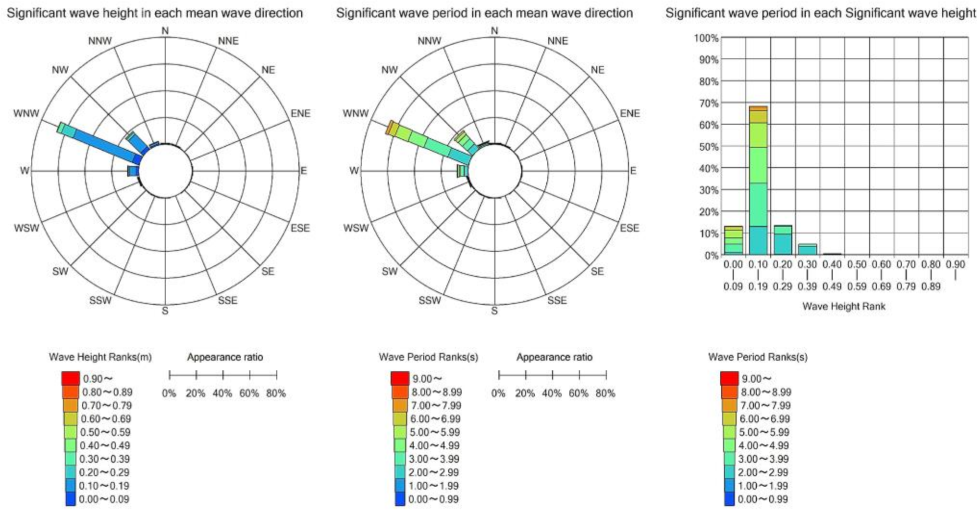
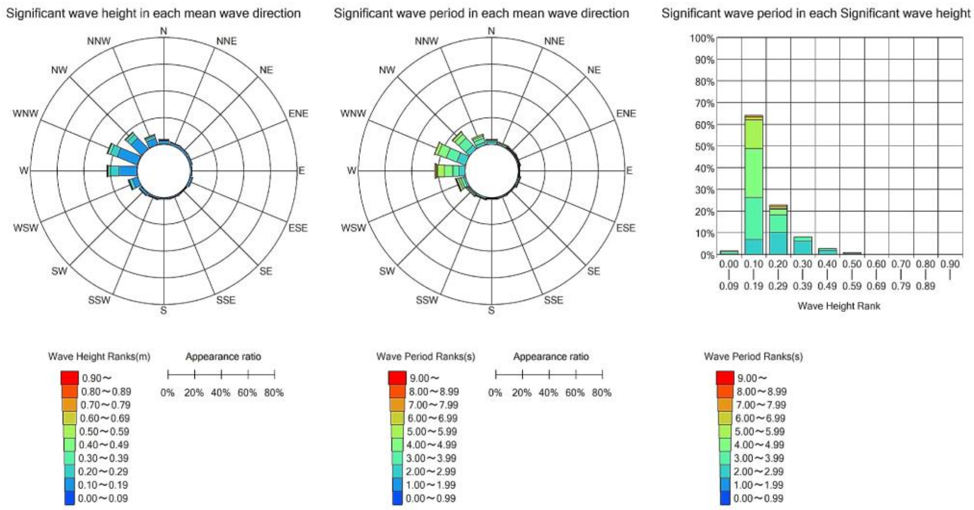


Figure 10-39 Observed Waves Inside Reef (dry season, 2014)

Observation point D1



Observation point D2



Observation point D3

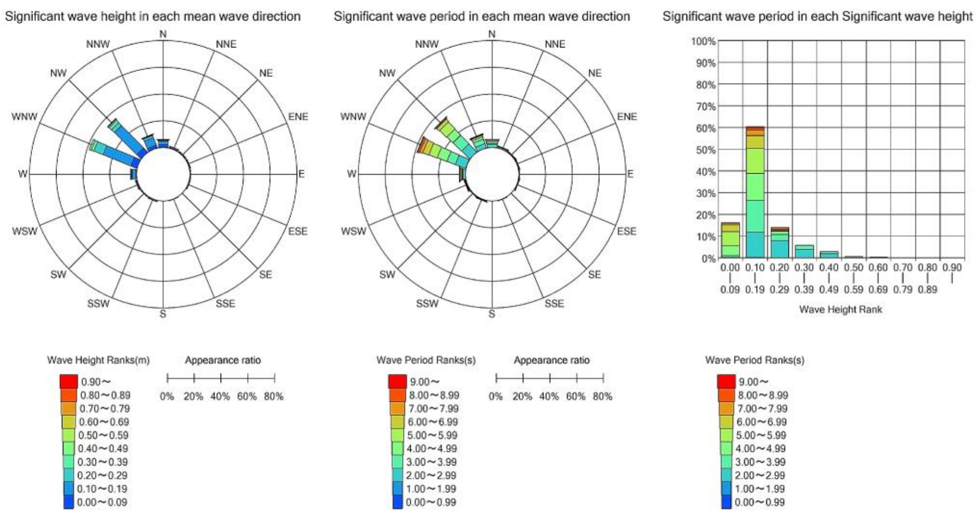


Figure 10-40 Observed Waves Inside Reef (rainy season, 2015)

10.3.3 Currents (Tidal Residual Currents)

As tidal residual currents are considered to have influence on the mass transport of seabed sediment, the measurement data taken with the current meters installed on the seabed were systematically analyzed.

A tidal residual current is obtained by removing the tidal constituents from an observed current (refer to Table 10-20). In most cases, the velocity of the residual currents thus obtained was small at the order of 1.0cm/s or below. Therefore, the comparison between the data of the dry and rainy seasons revealed no regularity or characteristic tendency of their directions as they were decided by the conditions of the time.

However, the velocity of residual current of 1.3cm/s was observed at C5 both in the dry and rainy seasons. As this point is located near the estuary of the Nadi River, it is assumed that the flow of river water has some effect on the residual current.

Table 10-20 Tidal Residual Currents

	Dry season (Aug. – Sep. 2014)		Rainy season (Jan. – Feb. 2015)	
	Velocity of the residual current (cm/s)	Direction (deg.)	Velocity of the residual current (cm/s)	Direction (deg.)
C1	0.6	350.9	0.4	306.5
C2	0.0	292.0	0.5	100.4
C3	0.9	247.1	2.4	27.9
C4	0.7	198.4	0.8	150.1
C5	1.3	88.9	1.3	10.7
C6	0.2	340.7	0.9	75.6

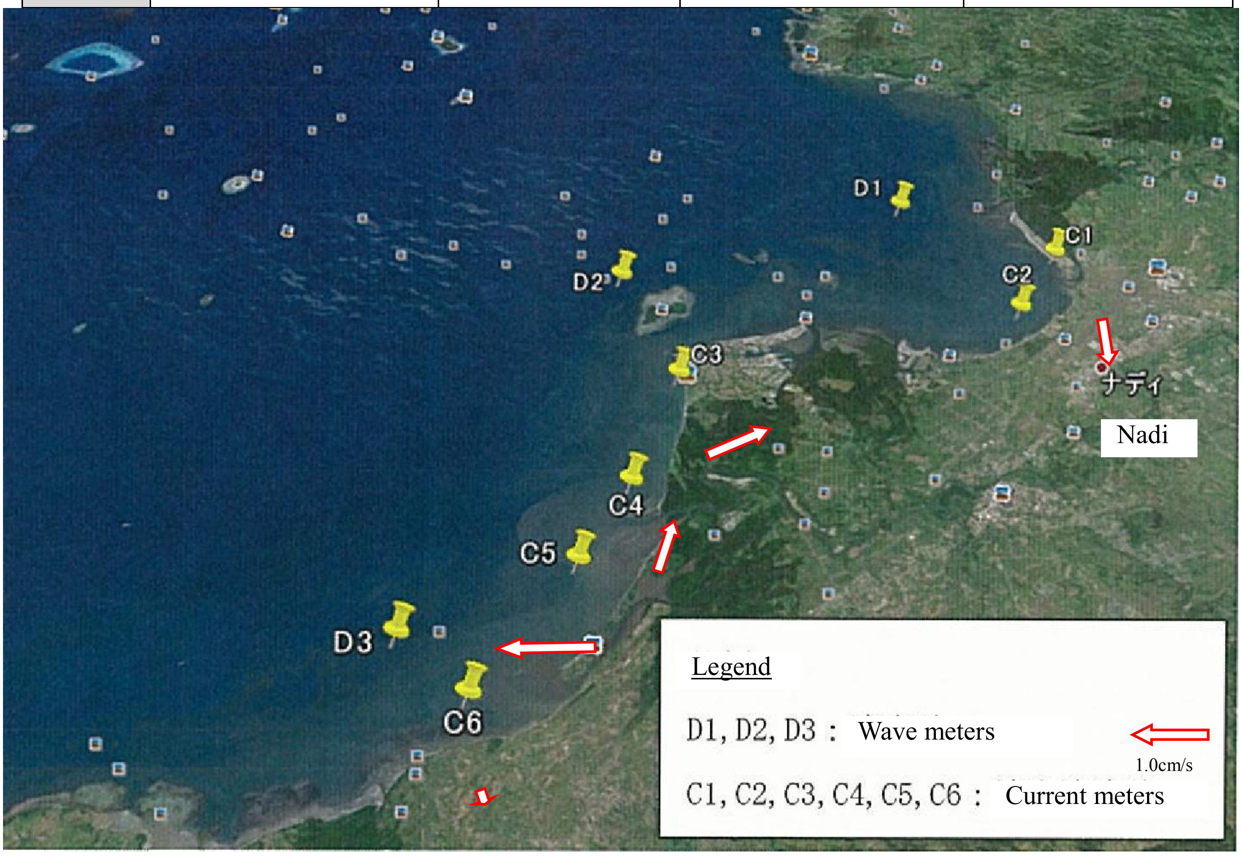


Figure 10-41 Direction and Velocity of Tidal Residual Currents (dry season)

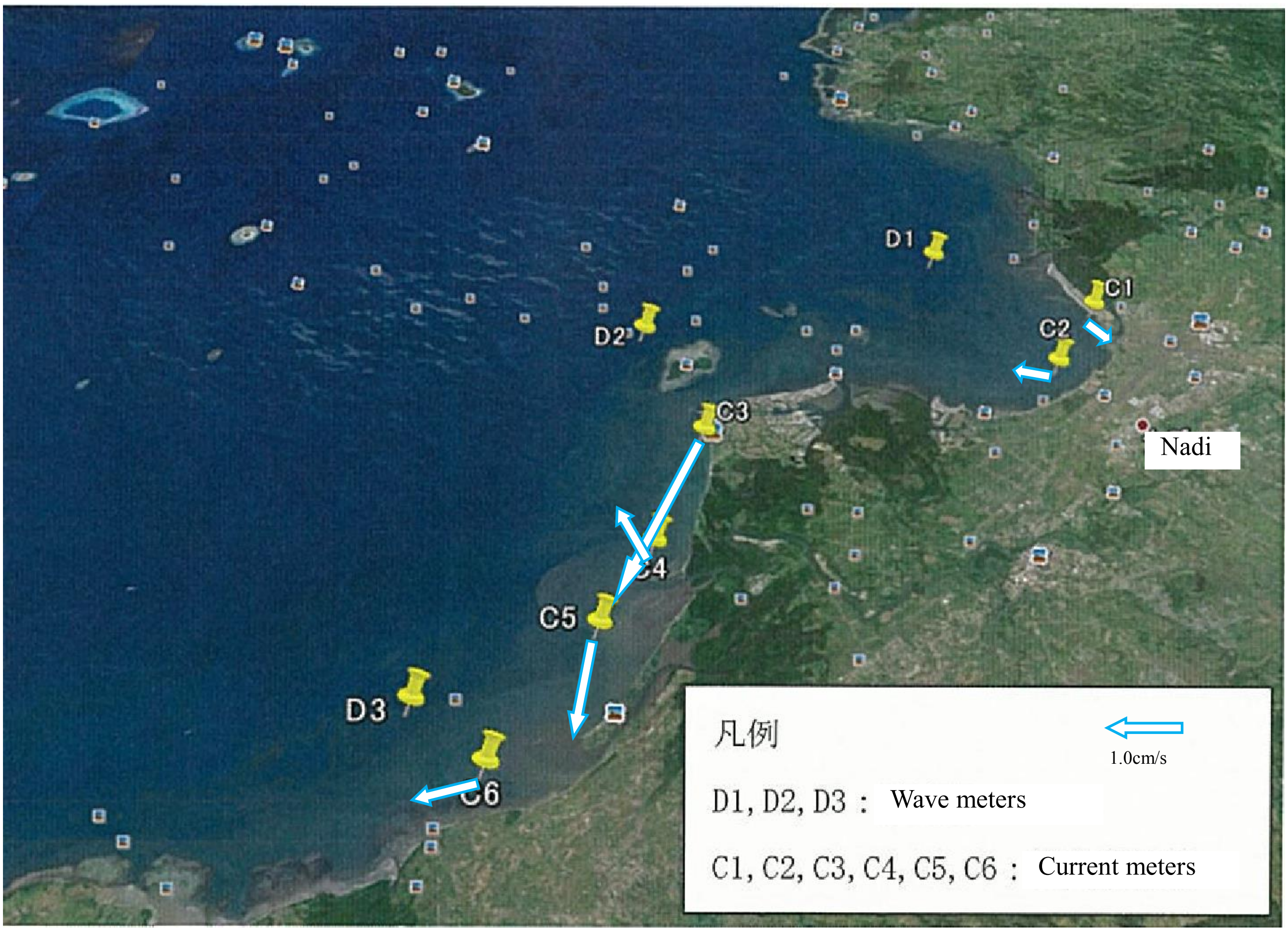


Figure 10-42 Direction and Velocity of Tidal Residual Currents (rainy season)

10.3.4 Seabed Materials

(1) Particle Size at Seabed

Figure 10-43 shows the particle size accumulation curves of the samples taken in Nadi Bay (on Line NL13) and at the estuary of the Nadi River (on Line SP13-17) as typical examples of the composition of particle size. All the curves have a steep rise in the range corresponding to the particle size between 0.05mm and 1.00mm, which indicates the predominance of particles in this diameter range. It is considered that the proportion of the particle of a specific diameter range is increased by the sieving effect of the waves.

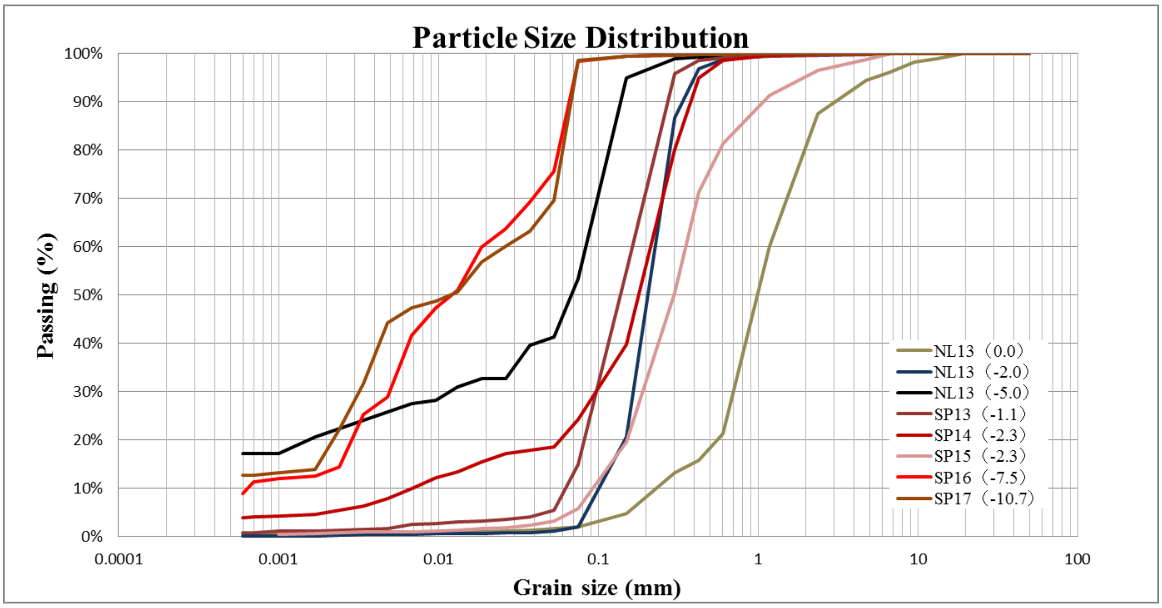


Figure 10-43 Particle Size Accumulation Curves of Seabed Materials

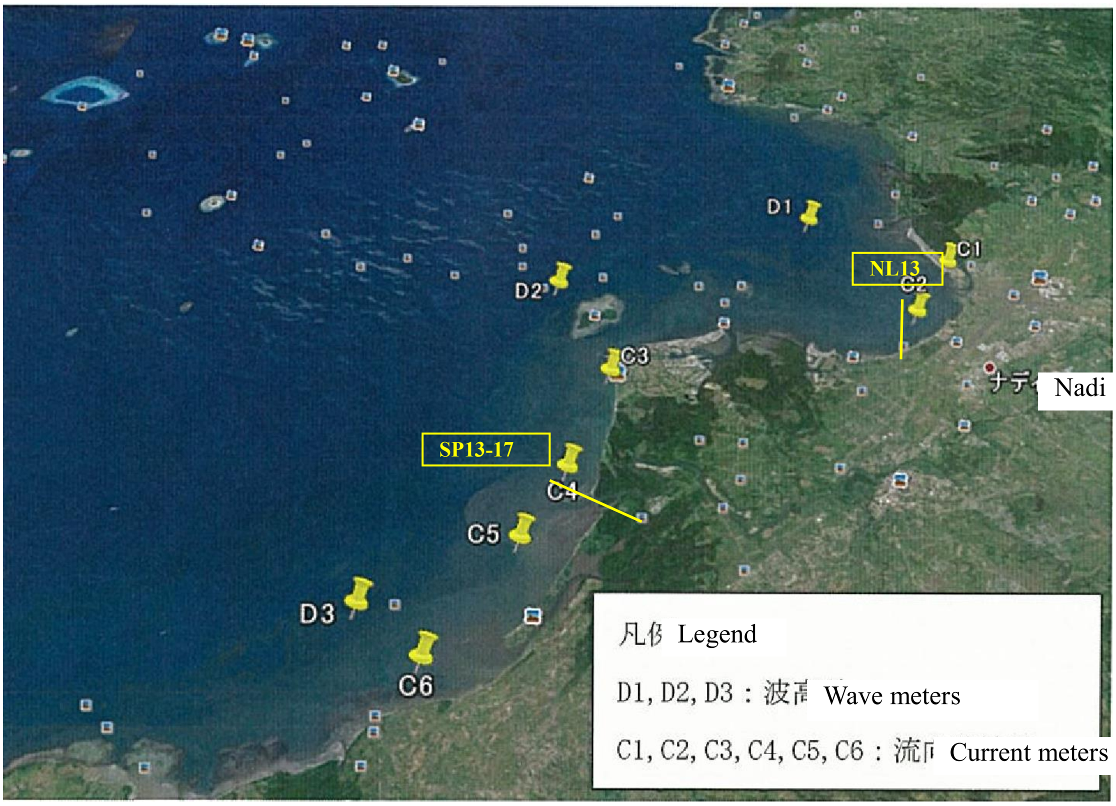


Figure 10-44 Sampling Locations of Seabed Materials

(2) Relationships between Depth and Particle Size

Table 10-21 and Figure 10-45 (1), Figure 10-45 (2) show the relationships between water depth and the results of the sediment tests. The particle size of sediment decreased as the water depth increased, as seen in the relationships between depth and 50% particle size d50. Similarly, the fine fraction contents Fc (the percentage of particles with a diameter of 75µm or less), increased linearly with the increase in the depth. The fine fraction content was 50% or more at the depth of 5m and below. At the depth of 7.5m or below, the fine fraction content is more than 98% and the bed material become silty.

As the fine fraction content increased, the characteristics of the seabed materials changed from those of sandy soil to clayey soil. The plasticity index of the sediment at the depth of 7.5m or below was between 20 and 30.

(3) Organic Matter Content (OMC)

The test results of loss on ignition revealed that the soil near the shoreline had almost no organic matters. However, organic matters were found in the sediment at the depth of -2m or below where the sediment had fine soil particles. OMC was below 10% in weight ratio.

(4) Density of soil particles

The mean of the density of soil particles was 2.733g/cm3. Relatively heavy soil particles with the density of 2.826 – 2.846 were found at the points on Line SP13-17 in shallow waters near the estuary of Nadi River. It is assumed that these heavy soil particles are not derived from coral reefs and that are mainly sediment discharge from river, large percentage of which are derived from lava with high mineral content.

Table 10-21 Test Results of Seabed Materials

	Water depth Depth (m)	50 % particle size d50 (mm)	Fine fraction content Fc (%)	Organic matter content OMC (%)	Water content Wc (%)	Density ρ (g/cm3)	Plasticity index Ip	Liquid limit WL (%)
SP13	-1.1	0.150	14.94	n/a	40.30	2.826	np	
SP14	-2.3	0.170	24.29	3.02	43.29	2.846	7.39	22.80
SP15	-2.3	0.300	5.85	n/a	26.53	2.717	np	
SP16	-7.5	0.012	98.40	8.64	95.51	2.625	23.08	56.00
SP17	-10.7	0.012	98.61	9.32	115.04	2.620	30.48	66.30
NL13	0.0	1.000	2.03	n/a	6.83	2.692	np	
NL13	-2.0	0.200	1.95	n/a	27.44	2.840	np	
NL13	-5.0	0.060	53.39	2.99	76.04	2.700	17.80	43.30

Water Content : Wc = (mass of water in soil) / (dry mass of soil) ×100(%)

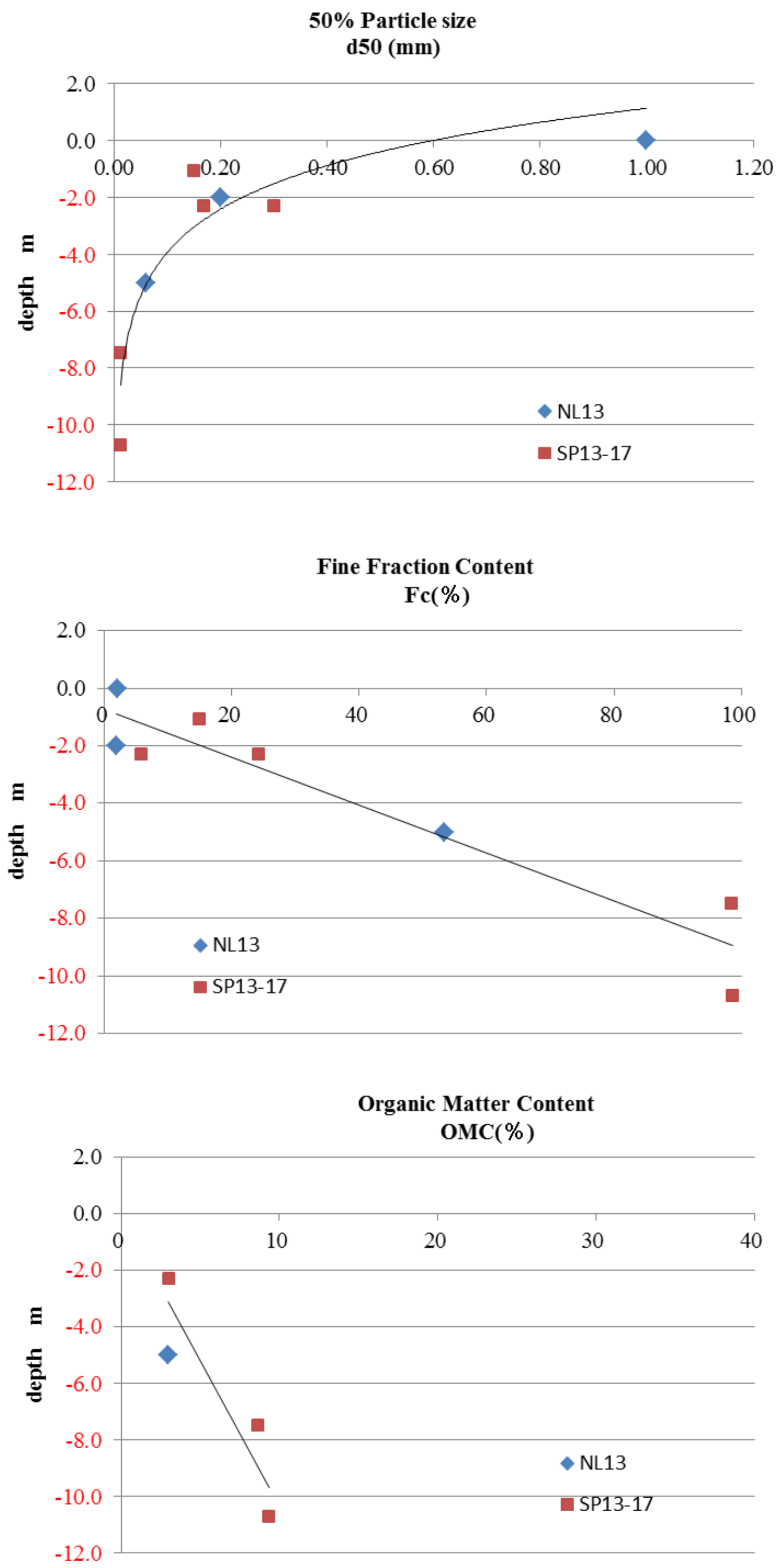


Figure 10-45 (1) Relationships between Water Depth and Characteristics of Sediment (Part 1)

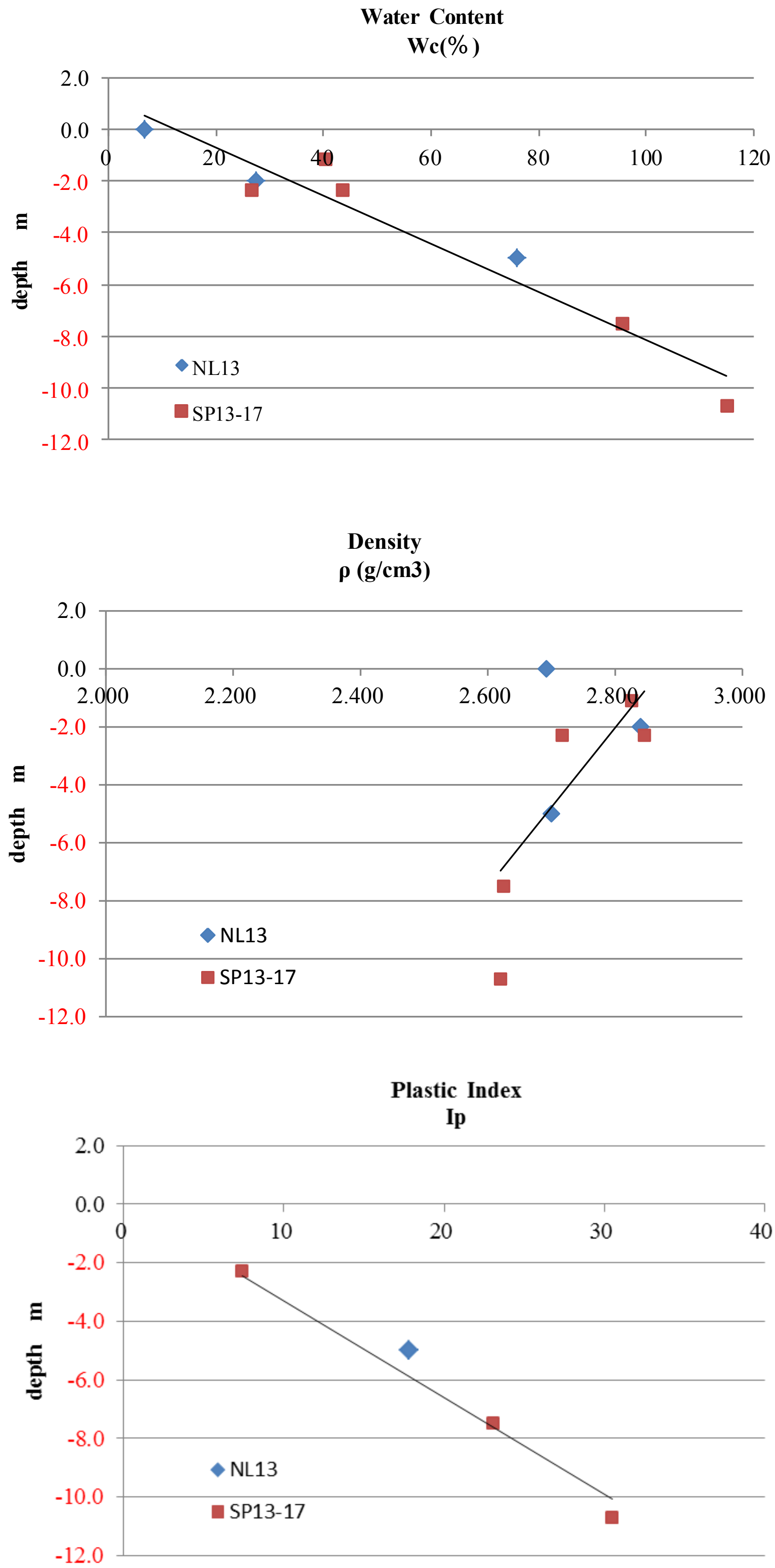


Figure 10-45 (2) Relationships between Water Depth and Characteristics of Sediment (Part 2)